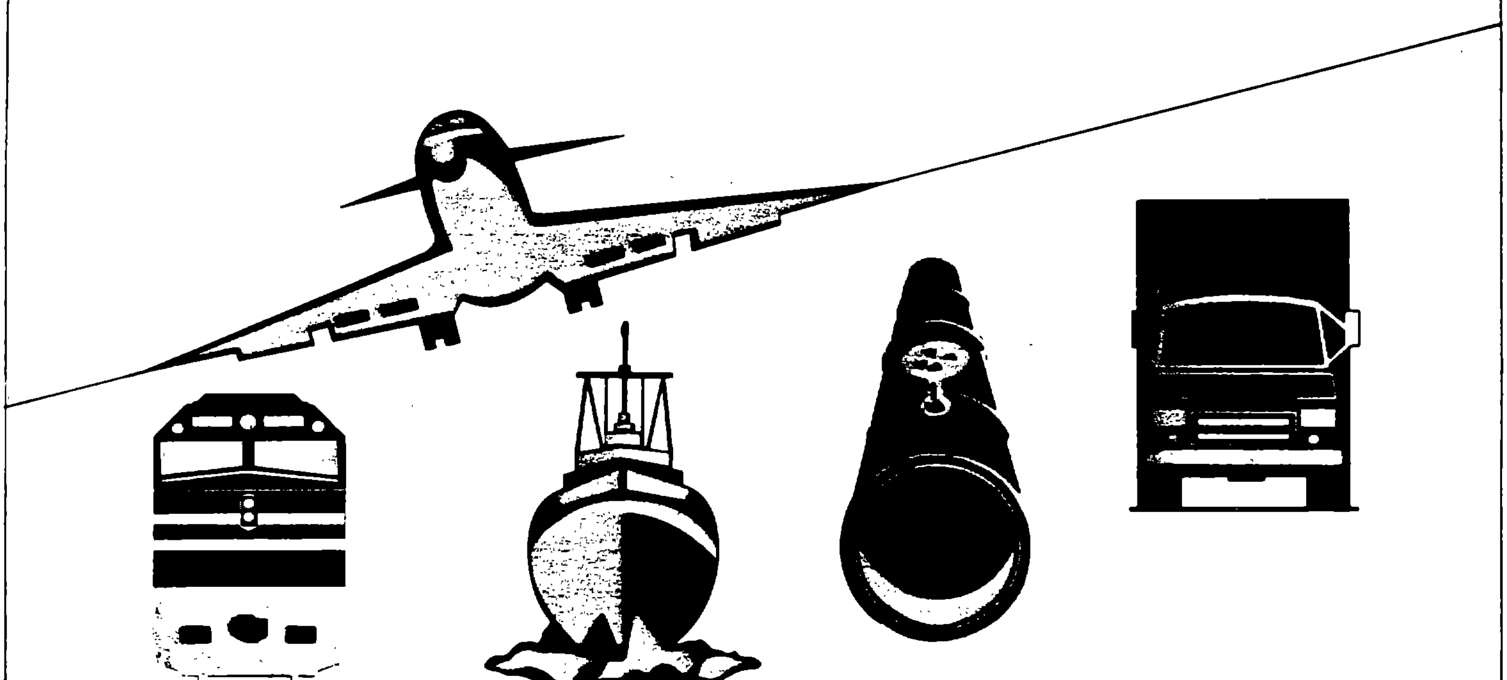
PB98-916611
NTSB/REC-98/11

NATIONAL TRANSPORTATION SAFETY BOARD

TRANSPORTATION SAFETY RECOMMENDATIONS

ADOPTED DURING THE MONTH OF NOVEMBER, 1998



TECHNICAL REPORT DOCUMENTATION PAGE

1. Report No. NTSB/REC-98/11	2. Government Accession No. PB98-916611	3. Recipient's Catalog No.
4. Title and Subtitle Transportation Safety Recommendations - Adopted during the month of September, 1998.		5. Report Date
		6. Performing Organization Code
7. Author(s)		8. Performing Organization Report No.
9. Performing Organization Name and Address National Transportation Safety Board Office of Safety Recommendations Washington, D. C. 20594		10. Work Unit No.
		11. Contract or Grant No.
12. Sponsoring Agency Name and Address NATIONAL TRANSPORTATION SAFETY BOARD Washington, D. C. 20594		13. Type of Report and Period Covered
		14. Sponsoring Agency Code
15. Supplementary Notes		

16. Abstract

This publication contains safety recommendations in aviation, highway, pipeline and railroad modes of transportation adopted by the National Transportation Safety Board during the month of September, 1998.

AVIATION

A-98-81 through 82
A-98-88 through 106
A-98-107 to 108
A-98-112
A-98-119 through 121
A-98-122 through 124

HIGHWAY

H-98-43 through 46
H-98-47
H-98-48
H-98-49

PIPELINE

P-98-30
P-98-31 through 33
P-98-34 through 38
P-98-39
P-98-40

RAILROAD

R-98-67 and 68

17. Key Words		18. Distribution Statement	
19. Security Classification (of this report) UNCLASSIFIED	20. Security Classification (of this page) UNCLASSIFIED	21. No. of Pages 112	22. Price

NTSB Form 1765.2 (Rev. 9/74)

National Transportation Safety Board
Washington, D.C. 20594

Safety Recommendation

Date: November 4, 1998
In reply refer to: A-98-81 through -82

Honorable Jane F. Garvey
Administrator
Federal Aviation Administration
Washington, D.C. 20591

On July 31, 1997, the Atlanta Air Route Traffic Control Center (ARTCC) reported an operational error resulting from its issuance of a clearance to Atlantic Southeast Airlines flight 805 to descend below the minimum instrument altitude (MIA) applicable to the area southwest of Asheville, North Carolina. The pilot received a ground proximity warning and climbed back to a safe altitude, reporting the incident to Atlanta ARTCC after landing. The National Transportation Safety Board requested information on this incident, including a copy of the Atlanta ARTCC MIA chart for the Asheville area. Inspection of this chart, used by controllers to determine safe operating altitudes for aircraft operating under instrument flight rules (IFR), revealed apparent noncompliance by the Atlanta ARTCC with various Federal Aviation Administration (FAA) handbooks and orders.

FAA Order 7210.3L, "Facility Operation and Administration," section 7-4-2, directs air traffic facilities to "determine minimum IFR altitude information for each control sector and display them at the sector. This shall include off-airway minimum IFR altitude information to assist controllers in applying FAR [Federal Aviation Regulation] Part 91.177 for off-airway vectors and direct route operations." This regulation requires that IFR operations be conducted at minimum altitudes of either 1,000 or 2,000 feet above terrain and obstacles along an aircraft's route of flight, except as necessary for takeoff or landing, or when a lower altitude is provided for a route, Federal airway, or instrument approach procedure under 14 Code of Federal Regulations (CFR) Parts 95 or 97. The 2,000-foot standard applies in areas designated as mountainous in Subpart B of 14 CFR Part 95, with 1,000-foot clearance applied elsewhere.

FAA Order 7210.37, "En Route Minimum IFR Altitude (MIA) Sector Charts," directs ARTCCs to develop MIA charts that comply with terrain and obstruction clearance requirements contained in FAA Orders 8260.3, "United States Standard for Terminal Instrument Procedures (TERPS handbook)," and 8260.19, "Flight Procedures and Airspace."

FAA Order 8260.19, chapter 3, section 7 provides instruction to the FAA flight standards personnel responsible for certifying that MIA charts submitted for review comply with required obstruction clearance criteria. Paragraph 362 of Order 8260.19, "Obstacle Clearance," states, "ATC will apply 1000 feet of obstacle clearance in non-mountainous areas and 2000 feet in areas designated as mountainous in FAR Part 95."

Paragraph 363 of Order 8260.19, "Obstacle Clearance Reduction," states the following:

> Where lower altitudes are required in designated mountainous areas to achieve compatibility with terminal routes or to permit vectoring to an instrument approach procedure, the FIAO [Flight Inspection Area Office] may approve reductions to the minimum altitude in accordance with the following ... ARSR [Air Route Surveillance Radar]: Reductions to not less than ... 1500 feet of terrain clearance may be authorized with appropriate obstacle clearance in accordance with en route criteria contained in TERPS, paragraph 1720b(1) and (2).

Paragraph 1720b(1) of the TERPS handbook is located in a section addressing the establishment of minimum en route altitudes (MEA) on Federal airways and provides, in part, the following:

1720. OBSTACLE CLEARANCE, PRIMARY AREA.

b. Mountainous Areas. Except as set forth in (1) and (2) below, the minimum obstacle clearance over terrain and manmade obstacles, within areas designated in FAR 95 as "mountainous" will be 2000 feet.

(1) Obstacle clearance may be reduced to not less than 1500 feet above terrain in the designated mountainous areas of the Eastern United States, Commonwealth of Puerto Rico, and the land areas of the State of Hawaii; and may be reduced to not less than 1700 feet above terrain in the designated mountainous areas of the Western United States and the State of Alaska. Consideration must be given to the following points before any altitudes providing less than 2000 feet of terrain clearance are authorized.

(a) Areas characterized by precipitous terrain.
(b) Weather phenomena peculiar to the area.
(c) Phenomena conducive to marked pressure differentials.
(d) Type of and distance between navigation facilities.
(e) Availability of weather services throughout the area.
(f) Availability and reliability of altimeter resetting points along airways/routes in the area.

The primary area referred to in the title of paragraph 1720 is defined in TERPS handbook paragraph 1711 as follows: "The primary en route obstacle clearance area extends from each radio facility on an airway or route to the next facility. It has a width of 8 NM; 4 NM on each side of the centerline of the airway or route." This definition of primary area describes the basic protected airspace along the centerline of a Federal airway and makes no reference to general off-airway terrain and obstruction clearance requirements.

Comparison of the Asheville-area MIA chart excerpt provided to the Safety Board by the FAA with a sectional chart covering the same region indicates that, at the time of the incident, Atlanta ARTCC was apparently using a 1,500-foot obstruction clearance standard to determine MIAs throughout that portion of its control area designated as mountainous terrain under 14 CFR Part 95. According to the previous references, the correct vertical separation minimum appears to be 2,000 feet, except along airways where a lower MEA has been established. At the time of the July 1997 incident, Atlanta ARTCC was applying the limited reductions in vertical separation permitted by TERPS to off-airway IFR terrain clearance in areas that clearly did not meet the standards for an exception, as specified in paragraph 363 of FAA Order 8260.19. As a result, IFR aircraft operating off airways in accordance with the minimum altitudes permitted by Atlanta ARTCC in the designated mountainous area under its control had less-than-standard terrain separation and might not have been operating in compliance with 14 CFR Part 91.177. Further, use of this MIA data as a basis for en route minimum safe altitude warning (E-MSAW) system adaptation would have also resulted in reduced warning time available from that system.

The Safety Board is concerned that the inadequate altitude margins in the Atlanta area were not detected through either the chart review process required by FAA Order 7210.37, "En route Minimum IFR Altitude Sector Charts," or as part of the national air traffic facility evaluation program. This condition suggests inadequacies in the FAA's quality assurance and review processes for both MIA chart certification and E-MSAW adaptation. Therefore, the Safety Board believes that the FAA should implement procedures that require explicit agreement between the agency's Flight Standards and Air Traffic services for the approval of charted MIAs that do not comply with the requirements of 14 CFR Part 91.177 and require a written explanation of the reasons for any permitted deviation from the standards of 14 CFR Part 91.177.

Further, the Safety Board is concerned that these inadequacies may not be limited to Atlanta ARTCC airspace. Therefore, the Safety Board believes that the FAA should review all en route MIA charts and associated National Airspace System adaptation to ensure that air traffic control (ATC) facilities comply with FAA Orders 7210.3, 7210.37, 8260.3, and 8260.19 and that pilots comply with 14 CFR Part 91.177 when operating at ATC-assigned altitudes.

Therefore, the National Transportation Safety Board recommends that the Federal Aviation Administration:

> Implement procedures that require explicit agreement between the agency's Flight Standards and Air Traffic services for the approval of charted minimum instrument altitudes that do not comply with the requirements of 14 Code of Federal Regulations (CFR) Part 91.177 and require a written explanation of the reasons for any permitted deviation from the standards of 14 CFR Part 91.177. (A-98-81)

> Review all en route minimum instrument altitude charts and associated National Airspace System adaptation to ensure that air traffic control (ATC) facilities comply with Federal Aviation Administration Orders 7210.3, 7210.37, 8260.3, and 8260.19 and that pilots comply with 14 Code of Federal Regulations Part 91.177 when operating at ATC-assigned altitudes. (A-98-82)

Chairman HALL, Vice Chairman FRANCIS, and Members HAMMERSCHMIDT, GOGLIA, and BLACK concurred in these recommendations.

By: Jim Hall
Chairman

National Transportation Safety Board

Washington, D.C. 20594

Safety Recommendation

Date: November 30, 1998

In reply refer to: A-98-88 through -106

Honorable Jane F. Garvey
Administrator
Federal Aviation Administration
Washington, D.C. 20591

About 1554 eastern standard time,[1] on January 9, 1997, an Empresa Brasileira de Aeronautica, S/A (Embraer) EMB-120RT, N265CA, operated by COMAIR Airlines, Inc.,[2] as flight 3272, crashed during a rapid descent after an uncommanded roll excursion near Monroe, Michigan. Comair flight 3272 was being operated under the provisions of Title 14 Code of Federal Regulations (CFR) Part 135 as a scheduled, domestic passenger flight from the Cincinnati/Northern Kentucky International Airport (CVG), Covington, Kentucky, to Detroit Metropolitan/Wayne County Airport (DTW), Detroit, Michigan. The flight departed CVG about 1508, with 2 flightcrew members, 1 flight attendant, and 26 passengers on board. There were no survivors. The airplane was destroyed by ground impact forces and a postaccident fire. Instrument meteorological conditions prevailed at the time of the accident, and flight 3272 was operating on an instrument flight rules flight plan.

The National Transportation Safety Board determined that the probable cause of this accident was the Federal Aviation Administration's (FAA) failure to establish adequate aircraft certification standards for flight in icing conditions, the FAA's failure to ensure that a Centro Tecnico Aeroespacial/FAA-approved procedure for the accident airplane's deice system operation was implemented by U.S.-based air carriers, and the FAA's failure to require the establishment of adequate minimum airspeeds for icing conditions, which led to the loss of control when the airplane accumulated a thin, rough accretion of ice on its lifting surfaces.[3]

---

[1] Unless otherwise indicated, all times are eastern standard time, based on a 24-hour clock.

[2] Within this safety recommendation letter, COMAIR Airlines, Inc., will be identified as Comair.

[3] National Transportation Safety Board. 1998. *In-Flight Icing Encounter and Uncontrolled Collision With Terrain, Comair Flight 3272, Embraer EMB-120RT, N265CA, Monroe, Michigan, January 9, 1997.* Aircraft Accident Report NTSB/AAR-98/04. Washington, DC.

6997A/B/C

Summary of Accident Sequence

According to cockpit voice recorder (CVR) and air traffic control (ATC) information, during the 20 minutes preceding the accident, the pilots received a series of clearances from ATC that included descent, airspeed, and heading instructions. Flight data recorder (FDR) and radar data indicated that the airplane's descent from the en route cruise altitude of flight level 210 to 4,000 feet mean sea level (msl) was stable and controlled and was accomplished at airspeeds and headings consistent with those assigned by ATC. Meteorological information and pilot reports indicated that the airplane was probably intermittently in clouds as it descended between about 11,000 feet msl and 8,200 feet msl; below 8,200 feet msl, the airplane was probably operating predominantly in the clouds.

The pilots were operating with the autopilot engaged during the descent. They had completed the descent checklist (including the activation of the propeller deicing and windshield heat at the ice protection checklist prompt) and the first four of the six items on the approach checklist[4] before the airplane reached 4,000 feet msl during its descent. At 1553:59, when the autopilot was leveling the airplane at 4,000 feet msl on a heading of 180°, the airplane was in the clean configuration (no flaps or gear extended) at an airspeed of about 166 knots (the pilots were beginning to reduce the airspeed to the ATC-assigned airspeed of 150 knots). At that time, ATC instructed the pilots of flight 3272 to turn left to a heading of 090°. Shortly after the pilots initiated the left turn (by selecting the assigned heading for the autopilot), the airplane reached its selected altitude and (at 1554:08) the autopilot automatically transitioned to the altitude hold mode. As the autopilot attempted to maintain the selected altitude, the airplane's angle-of-attack (AOA) began to increase and the airspeed continued to decrease; at 1554:10, the autopilot began to trim the elevator (pitch trim) to an increasingly nose-up position.

The accident airplane's FDR data indicated that at 1554:10 the airplane's left bank steepened beyond 20° (moving toward the autopilot's command limit in the heading mode of 25°, +/- 2.5°). At that point (according to the autopilot design and FDR information), the roll rate exceeded that required by the autopilot's design logic to achieve the commanded roll angle, and the autopilot's input to the aileron servos moved the ailerons (and thus the airplane's control wheel) in the right-wing-down (RWD) direction to counter the increasing left roll rate. FDR data indicated that, during the next 3 seconds, the left and right AOA vanes began to diverge, indicating a left sideslip/yaw condition, and the lateral acceleration values began to increase to the left while the autopilot increased the control wheel input to the right in an attempt to control the roll. Thus, by 1554:10, as the airspeed decreased through 155 knots, the airplane experienced the beginning of a significant asymmetry in the lift distribution between the right and left wings and an uncommanded yaw and roll to the left.[5] The roll and control wheel position parameters continued to trend in opposite directions, and the left and right AOA vanes continued to split for the next 14 seconds, until the autopilot disconnected at 1554:24.125.

---

[4] According to several Comair EMB-120 pilots, the remaining approach checklist items—flight attendants, notified and flaps, 15/15/checked—would normally be accomplished later during the approach, as the airplane neared the destination airport.

[5] Evaluation of the FDR information revealed that a slight asymmetry of lift because of ice existed earlier in the flight; however, it became aerodynamically significant about 1554:10.

Just after 1554:15, as the airplane's airspeed began to decrease below 150 knots, the pilots began to increase the engine power;[6] however, the airplane's airspeed continued to decrease. When the captain drew the first officer's attention to the low airspeed indication at 1554:20.8, the airplane's airspeed had decreased to 147 knots. During the next 2 seconds, the pilots more aggressively increased the engine power, and a significant torque split occurred; the torque values peaked at 108 percent on the left engine and 138 percent on the right engine. The Safety Board considered several possible reasons for the significant torque split, including uneven throttle movement by the pilots, ice ingestion by the left engine, a misrigged engine, or an improper engine trim adjustment on the newly installed right engine; however, it was not possible to positively determine the cause of the torque split. Postaccident simulations indicated that this torque split had a significant yaw-producing effect at a critical time in the upset event, exacerbating the airplane's excessive left roll tendency. The airplane's airspeed decreased further to 146 knots, the left roll angle increased beyond the autopilot's 45° limit, and (at 1554:24.1) the autopilot disconnect warning began to sound. One second later, the stick shaker activated. The sudden disengagement of the autopilot (at 1554:24.125) greatly accelerated the left rolling moment that had been developing, suddenly putting the airplane in an unusual attitude. Although the pilots were likely surprised by the upset event, interpretation of the FDR data indicated that the pilots responded with control wheel inputs to counter the left roll within 1 second of the autopilot disengagement and continued to apply control inputs in an apparent attempt to regain control of the airplane until the FDR recording ceased.

Meteorological Factors

Although Comair flight 3272 was operating in winter weather conditions throughout its flight from the Cincinnati area to Detroit, CVR and weather information indicated that the airplane was operating above the cloud tops at its cruise altitude of 21,000 feet msl. Further, the temperatures at the altitudes flown during the en route phase of the flight were too cold to be conducive to airframe ice accretion, and examination of the FDR data did not reflect degraded airplane performance until later in the airplane's descent. Therefore, the Safety Board concludes that the airplane was aerodynamically clean, with no effective ice accreted, when it began its descent to the Detroit area.

A study conducted by the National Center for Atmospheric Research (NCAR) indicated that there was strong evidence for the existence of icing conditions in the clouds along the accident airplane's descent path below 11,000 feet msl. In addition, weather radar data showed generally light precipitation intensities in the area west of Detroit, with weather echoes of increasing intensity below 11,000 feet msl along the airplane's descent path. The weather radar data indicated that the highest precipitation intensities likely existed between 4,100 feet msl and 3,900 feet msl.

---

[6] An engine torque split manifested itself during this application of power—at 1554:17, the FDR recorded torque values of 33.3 percent and 39.3 percent on the left and right engines, respectively. The engine torque split ranged from 6 to 10 percent between 1554:17 and 1554:22, when torque values (and the range of the torque split) began to increase abruptly. Simulator test flights that replicated the accident scenario demonstrated that the initial 6 to 10 percent torque split did not have a large aerodynamic effect on the airplane's left roll; however, the larger torque split that occurred later in the accident sequence had a significant aerodynamic effect.

The NCAR research meteorologists reported that the average liquid water content (LWC) in the clouds near the accident site likely varied from 0.025 to 0.4 grams per cubic meter when averaged over the cloud depth. However, according to an NCAR research meteorologist, droplet size and LWC are rarely evenly distributed through the depth of a cloud; he stated that, in a typical cloud distribution, the larger droplet sizes with corresponding lower LWC would likely exist near the cloud bases, whereas smaller droplet sizes with higher LWC would typically exist near the cloud tops. He stated that the accident airplane might have encountered higher LWC values (0.5-0.8 grams per cubic meter) with smaller droplets (non-supercooled large droplets (SLD), 10-30 microns) near the cloud tops and lower LWC values (0.025 to 0.4 grams per cubic meter) with larger droplets (larger than 30 microns) near the cloud bases (consistent with the previously discussed weather radar data). Further, the NCAR research meteorologist stated, "if any SLD existed...it would have been more likely to be lower in the cloud...be mixed with smaller drops...the larger drops in the spectrum of those that may have existed there would have been in the 200-400 micron...range."

In addition, the accident airplane's descent path passed through an area of relatively low radar reflectivity during the 4 to 5 minutes before the accident. According to the NCAR report, the area of reduced reflectivity indicated that "the snow-making process was less efficient there, thus allowing a greater opportunity for liquid cloud to exist." Postaccident statements obtained from the other pilots who were operating along the accident airplane's flightpath (and passed through the area of low reflectivity) near the time of the accident indicated that they encountered widely variable conditions. For example, the pilots of Cactus 50 reported moderate rime icing with the possibility of freezing drizzle, the pilots of Northwest Airlines (NW) flight 272 encountered moderate-to-severe rime icing as soon as they leveled off at 4,000 feet msl, and the pilots of NW flight 483 reported no icing.

Comparison of data from the airplanes indicates that the differences in airframe ice accretion reported by the pilots can be attributed to slight differences in timing, altitude, location (ground track), airspeed, and icing exposure time (and time within the area of reduced reflectivity) of the airplanes. Based on weather radar information and pilot statements, the Safety Board concludes that the weather conditions near the accident site were highly variable and were conducive to the formation of rime or mixed ice at various altitudes and in various amounts, rates, and types of accumulation; if SLD icing conditions were present, the droplet sizes probably did not exceed 400 microns and most likely existed near 4,000 feet msl.

Aerodynamic Effect of the Ice Accretion

To help assess the type, amount, and effect of the ice that might have been accumulated by Comair flight 3272 during its descent, the Safety Board reviewed the available icing and wind tunnel research data, conducted additional airplane performance studies/simulations, and requested the National Aeronautics and Space Administration's (NASA's) assistance in conducting icing research tunnel (IRT) tests and computational studies. In addition, the Safety Board reviewed wind tunnel test data obtained during research conducted by the FAA at the University of Illinois at Urbana/Champaign (UIUC).

The Safety Board's study of the accident airplane's aerodynamic performance indicated that it began to degrade from ice accumulation[7] about 4½ to 5 minutes before the autopilot disengaged, as the airplane descended through 7,000 feet msl; the amount of degradation increased gradually as the airplane descended to 4,000 feet msl. Based on this gradual performance degradation, weather radar data that showed light precipitation intensities, pilot reports of moderate or less ice accretions,[8] and the Safety Board and NCAR weather studies, it appeared likely that Comair flight 3272 encountered icing conditions that fell within the 14 CFR Part 25 appendix C envelope[9] and/or the lower portion of the SLD icing range during its descent to 4,000 feet msl. Thus, the postaccident icing tunnel tests were performed using LWCs between 0.52 and 0.85 grams per cubic meter and water droplet sizes between 20 microns and 270 microns. Total air temperatures (TAT) used in the icing tunnel tests ranged between 26° F and 31° F (-3° C and -0.5° C),[10] consistent with the static air temperature (SAT) values recorded by the FDR during the airplane's descent from 7,000 to 4,000 feet msl. The exposure time used in the icing tunnel tests was 5 minutes; additional runs were conducted under some test conditions to determine the effect that deicing boot activation had on cleaning the leading edge and on subsequent ice accretions.

The icing tunnel tests did not result in thick ice accumulation under any test condition (including SLD droplets); rather, the tests consistently resulted in a thin (0.25 inch accumulation or less), rough "sandpaper-type" ice coverage over a large portion of the airfoil's leading edge deicing boot surface area (and aft of the deicing boot on the lower wing surface in some test conditions). In addition, in many IRT test conditions, small (½ inch) ice ridges accreted along the leading edge deicing boot seams. According to NASA and Safety Board IRT test observers, the thin, rough ice coverages (and ice ridges, where applicable) that accreted on the EMB-120 wing were somewhat translucent and were often difficult to perceive from the observation window. The IRT observers further noted that IRT lighting conditions and cloud (spray) type greatly affected the conspicuity of the ice accumulation, making it difficult to perceive the ice accumulation during the icing exposure periods. Scientists at NASA's Lewis Research Center described the IRT ice accretions as mostly "glaze" ice, like mixed or clear ice in nature, although it looked slightly like rime ice when the IRT was brightly lighted for photographic documentation of the ice accretions because of its roughness. The Safety Board notes that it is possible that such an accumulation would be difficult for pilots to perceive visually during flight, particularly in low light conditions. This type of accumulation would be consistent with the accident airplane's CVR, which did not record any crew discussion of perceived ice accumulation and/or the need to activate deicing boots during the last 5 minutes of the accident flight.

---

[7] Although the Safety Board considered other possible sources for the aerodynamic degradation (such as a mechanical malfunction), the physical evidence did not support a system or structural failure, and the FDR data indicated a gradual, steadily increasing performance degradation that was consistent with degradation observed by the Safety Board in data from events in which icing was a known factor.

[8] All pilot reports indicated moderate or less ice accretions, except the pilots of NW flight 272, who reported that they encountered a trace of rime ice during the descent, then encountered moderate-to-severe icing at 4,000 feet msl about 2 minutes after the accident.

[9] The Part 25 appendix C icing envelope specifies the water drop mean effective diameter, the LWC, and the temperatures at which the airplane must be able to safely operate; aircraft compliance must be demonstrated through analysis, experimentation, and flight testing.

[10] These TATs are equivalent to SATs of 21° F (-6° C) to 25.5° F (-3° C).

The location of rough ice coverage observed during the icing tunnel tests varied, depending on AOA; at lower AOAs, the ice accretions extended farther aft on the upper wing surface (to the aft edge of the deicing boot on the upper wing surface, about 7 percent of the wing chord at the aileron midspan), whereas at higher AOAs, the ice accretions extended farther aft on the lower wing surface. In some IRT test conditions, sparse feather-type ice accretion extended aft of the deicing boot coverage on the lower wing surface (which extends to about 10½ percent of the airfoil chord at the aileron midspan) as far as 30 to 35 percent of the airfoil's chord.[11]

The density of the rough ice coverage also varied, depending on the exposure time; a sparse layer of rough ice usually accreted on the entire impingement area during the first 30 seconds to 1 minute of exposure, and the layer became thicker and more dense as exposure time increased. The NASA-Lewis and FAA/UIUC tests indicated that thin, rough ice accretions located on the leading edge and lower surface of the airfoil primarily resulted in increases in drag, while thin, rough ice accretions located on the leading edge and upper wing surface had an adverse effect on both lift and drag; this is consistent with information that has been obtained during National Advisory Committee for Aeronautics (NACA)/NASA icing research conducted since the late 1930s. Data from research conducted in the 1940s and 1950s indicate that an airfoil's performance can be significantly affected by even a relatively small amount of ice accumulated on the leading edge area, if that accumulation has a rough, sandpaper-type surface.

Consistent with these data, NASA's drag calculations indicated that the thin, rough layer of sandpaper-type ice accumulation resulted in significant drag and lift degradation on the EMB-120 wing section. Further, the thin rough ice accumulation resulted in a decrease in stall AOA similar to that observed in wind tunnel tests with 3-inch ram's horn ice shapes on protected surfaces and frequently demonstrated a more drastic drop off/break at the stall AOA. FAA/UIUC conducted wind tunnel tests using generic shapes to represent the sandpaper-type roughness with ridges placed on the upper wing surface at 6 percent of the wing chord (farther aft than the ice ridges observed during NASA's IRT tests); these tests further demonstrated that the ridge type of ice accretion resulted in more adverse aerodynamic effect than the 3-inch ram's horn ice shapes.

As previously noted, NASA's IRT tests indicated that when an EMB-120 wing is exposed to conditions similar to those encountered by Comair flight 3272 before the accident, the airfoil tended to accrete a small ice ridge (or ridges) along the deicing boot tube segment stitchlines.

[11] According to NASA-Lewis scientists, some of the frost accretion observed aft of the deicing boot on the lower wing surface during the icing tunnel tests might have been an artifact of the icing research tunnel (resulting from the higher turbulence, humidity, and heat transfer characteristics of the tunnel). However, the B.F. Goodrich ice impingement study (which predicts ice accretion impingement limits on an airfoil) and NASA's LEWICE computer program (which predicts the extent of ice accretion on the leading edges of airplane wings and impingement limits and ice thickness for specified conditions but cannot predict surface roughness features) also predicted a sparse, rough ice accretion aft of the deicing boot on the lower wing surface for some of the tested conditions. However, no ice accretion aft of the deicing boot was noticed during the natural icing certification tests. Although it is possible that some of the drag observed in the accident airplane's performance was the result of a sparse, rough ice accumulation aft of the deicing boot on the lower wing surface, it was not possible to positively determine whether the accident airplane's ice accretion extended beyond the deicing boot coverage.

During tests conducted at a TAT of 26° F, a small, but prominent (½ inch) ridge of ice frequently appeared on the forward portion (0.5 to 1 percent mean aerodynamic chord) of the leading edge deicing boot's upper surface.

The IRT test results were used in NASA's computational studies, which indicated that these pronounced ice ridges tended to act as stall strips, creating more disrupted airflow over the airfoil's upper surface, further decreasing the lift produced by the airfoil, and resulting in a lower stall AOA than the rough ice accretions alone. NASA's computational study data indicated that a thin, rough ice accretion with a small, prominent ice ridge can result in a lower stall AOA and a more dramatic drop off/break than the 3-inch ram's horn ice shape commonly used during initial icing certification testing.

The accident airplane's performance displayed evidence of adverse effects on both lift and drag during the airplane's descent to 4,000 feet msl. The degradation exhibited by the accident airplane was consistent with a combination of thin, rough ice accumulation on the impingement area (including both upper and lower wing leading edge surfaces), with possible ice ridge accumulation. Thus, based on its evaluation of the weather, radar, drag information, CVR, existing icing research data, and postaccident icing and wind tunnel test information, the Safety Board concludes that it is likely that Comair flight 3272 gradually accumulated a thin, rough glaze/mixed ice coverage on the leading edge deicing boot surfaces, possibly with ice ridge formation on the leading edge upper surface, as the airplane descended from 7,000 feet msl to 4,000 feet msl in icing conditions; further, this type of ice accretion might have been imperceptible to the pilots.

The Safety Board notes that FAA Order 7110.10L, "Flight Services," contains a definition of "trace" ice accumulations, that states, in part, "A trace of ice is when ice becomes perceptible....It is not hazardous even though deicing/anti-icing equipment is not utilized unless encountered for an extended period of time [over 1 hour]." Information obtained during this investigation, which echoed the results of research conducted in the 1930s and 1940s, indicated that thin, rough amounts of ice, even in trace amounts can result in hazardous flight conditions. The Safety Board concludes that the suggestion in current FAA publications that "trace" icing is "not hazardous" can mislead pilots and operators about the adverse effects of thin, rough ice accretions. Therefore, the Safety Board believes that the FAA should amend the definition of trace ice contained in FAA Order 7110.10L, "Flight Services;" (and in other FAA documents as applicable) so that it does not indicate that trace icing is not hazardous.

The Safety Board notes that in some icing exposure scenarios, pilots could become aware of the performance degradation without observing a significant accumulation of ice on the airplane by observing other cues, such as a decrease in airspeed, excessive pitch trim usage, a higher-than-normal amount of engine power needed to maintain a stabilized condition, and/or anomalous rates of climb or descent. However, the Safety Board concludes that because the pilots of Comair flight 3272 were operating the airplane with the autopilot engaged during a series of descents, right and left turns, power adjustments, and airspeed reductions, they might not have perceived the airplane's gradually deteriorating performance.

Further, although it is possible (based on the icing reported by the pilots of NW flight 272 and the NCAR scientist's estimation of the likely droplet size distribution in the clouds) that the accident flight encountered SLD icing[12] as it reached 4,000 feet msl, the airplane was only at that altitude for about 25 seconds before the upset occurred; during most of that 25 seconds, the FDR data showed that the autopilot was countering the increasing left roll tendency and a sideslip condition was developing. However, even if the accident flight had accumulated ice at the rapid rate reported by the pilots of NW flight 272 (about ½ inch per minute), the accident flight could not have accumulated a large amount of ice during the brief period of time it spent at 4,000 feet before the autopilot disengaged and the loss of control occurred. Further, icing of the magnitude described by the pilots of NW flight 272 would have produced strong visual cues, and it is likely that the pilots would have commented on such a rapid accumulation, had it occurred. The accident airplane's CVR did not record any flightcrew comments about ice accumulation or the need to activate the leading edge deicing boots during the last 5 minutes of the accident flight; this is consistent with an ice accumulation that was either not observed by the pilots or that was observed but considered to be unremarkable.

Use of Deice/Anti-ice Equipment

The Safety Board attempted to determine whether the airplane's ice protection systems were operated during the accident airplane's descent and approach to DTW. CVR information showed that when the pilots performed the descent checklist at 1547, they confirmed that the airplane's "standard seven" anti-ice systems were activated and activated the windshield heat and the propeller deice system.[13] This was consistent with guidance contained in Comair's EMB-120 Flight Standards Manual (FSM), which stated that anti-ice systems should be activated "before flying into known icing conditions" to prevent ice accumulation on the affected surfaces. Comair's EMB-120 FSM defined icing conditions as existing "when the OAT [outside air temperature] is +5° C or below and visible moisture in any form is present (such as clouds, rain, snow, sleet, ice crystals, or fog with visibility of one mile or less)."

For years, airplane manufacturers have incorporated leading edge deicing boots in the design of airplanes that are to be certificated for operation in icing conditions; the purpose of deicing boots is to shed the ice that accumulates on protected surfaces of the airframe. Over the years, leading edge deicing boots have demonstrated their effectiveness to operators and pilots by keeping the wing and tail leading edges relatively clear of aerodynamically degrading ice accumulations, to the point that operators and pilots have become confident that the airplanes can be flown safely in icing conditions as long as the airplane's deicing boots are operated (and functioning) properly. However, based on problems with earlier deicing boot designs (which used larger tubes and lower pressures, resulting in slower inflation/deflation rates), manufacturers, operators, and pilots developed the belief that premature activation of the leading edge deicing boots could (as cautioned in Comair's EMB-120 FSM) "result in the ice forming the shape of an

[12] Results from the SLD icing tanker tests suggest that the visual cues for SLD ice accumulations (unusually extensive ice accreted on the airframe in areas not normally observed to collect ice, accumulation of ice on the upper surface of the wing aft of the protected area, and on the propeller spinner farther aft than normally observed) would have been very apparent to the pilots and might have resulted in a comment.

[13] Although Embraer's nomenclature identifies the propeller ice protection mechanism as a deicing system, it functions as an anti-icing system because it is activated before ice accumulates on the airframe.

inflated de-ice boot, making further attempts to deice in flight impossible [ice bridging]." Thus, at the time of the accident, Comair's (and most other EMB-120 operators') guidance indicated that pilots should delay activation of the leading edge deicing boots until they observed ¼ inch to ½ inch ice accumulation, despite Embraer's FAA and Centro Tecnico Aeroespacial of Brazil (CTA) approved EMB-120 Airplane Flight Manual (AFM) revision 43, which indicated that pilots should activate the leading edge deicing boots at the first sign of ice accumulation.

The pilots' activation of the propeller and windshield ice protection systems when the airplane entered the clouds would indicate that they were aware that the airplane was operating in icing conditions. If they had activated the leading edge deicing boots, at least some of the airplane's degraded performance would have been restored. However, even if the pilots observed any of the thin, rough ice accretion that likely existed before the loss of control, they probably would not have activated the deicing boots because Comair's guidance to its pilots advised against activating the deicing boots until they observed a thicker ice accumulation. Therefore, based on CVR information and on the steady degradation of airplane performance that was clearly uninterrupted by leading edge deicing boot activation, the Safety Board concludes that, consistent with Comair's procedures regarding ice protection systems, the pilots did not activate the leading edge deicing boots during their descent and approach to the Detroit area, likely because they did not perceive that the airplane was accreting significant (if any) structural ice.

During the postaccident (November 1997) Airplane Deicing Boot Ice Bridging Workshop, information regarding recent icing tunnel and flight test research into the ice bridging phenomenon was disseminated and discussed among industry personnel. The recent research revealed that modern turbine-powered airplanes, with their high-pressure, segmented pneumatic deicing boots, are not at risk for ice bridging.[14] However, in April 1996 when Embraer issued (FAA- and CTA-approved) revision 43 to the EMB-120 AFM, the procedure it recommended—activation of the leading edge deicing boots at the first sign of ice accretion—was not consistent with traditional industry concerns about ice bridging. According to the FAA's EMB-120 Aircraft Certification Program Manager, when the EMB-120 AFM revision was proposed by Embraer in late 1995, the deicing boot procedural change was very controversial and generated numerous discussions among FAA and industry personnel. The FAA's EMB-120 Aircraft Certification Program Manager stated that the aircraft evaluation group (AEG) personnel involved in the discussions about the six EMB-120 icing-related events, the EMB-120 in-flight icing tanker tests, and the deicing boot procedural change were initially resistant to the deicing boot procedural change because of the perceived potential for ice bridging.

The Safety Board notes that during the winter of 1995/1996, senior Comair personnel (and representatives from other EMB-120 operators) were involved in numerous meetings and discussions regarding the six preaccident icing-related events and that they subsequently received Embraer's Operational Bulletin (OB) 120-002/96 and revision 43 to the EMB-120 AFM, with its controversial deicing boot procedural change. Although these discussions and documents apparently heightened senior Comair personnel's awareness and concern about EMB-120 operations in icing conditions (as evidenced by the December 1995 interoffice memo, entitled

[14] It is important to note that ice bridging may still be a potential hazard for airplanes with older technology deicing boots that have slower inflation/deflation rates.

"Winter Operating Tips," and the October 1996 flight standards bulletin (FSB) 96-04, entitled "Winter Flying Tips"), until the (postaccident) ice bridging workshop, there was insufficient information available to allay the company's concerns regarding the perceived hazards of ice bridging. Because Comair management personnel were still concerned that ice bridging was a problem for modern turbopropeller-driven airplanes, at the time of the accident, the company's deicing boot activation procedures had not been revised in accordance with AFM revision 43. The Safety Board recognizes the concerns regarding ice bridging that Comair had at the time of the accident (before the ice bridging workshop) and notes that the FAA had not mandated incorporation of the procedural revision or engaged in discussions with EMB-120 operators/pilots regarding the merit of the procedural change. Apparently, Comair was not the only EMB-120 operator with concerns regarding the deicing boot procedural change because the air carriers' records indicated that at the time of the accident, only two of seven U.S.-based EMB-120 operators had incorporated the revision into its procedural guidance. However, the Board is concerned that Comair's EMB-120 pilots did not have access to the most current information regarding operating the EMB-120 in icing conditions.

The Safety Board concludes that had the pilots of Comair flight 3272 been aware of the specific airspeed, configuration, and icing circumstances of the six previous EMB-120 icing-related events and of the information contained in OB 120-002/96 and revision 43 to the EMB-120 AFM, it is possible that they would have operated the airplane more conservatively with regard to airspeed and flap configuration or activated the deicing boots when they knew they were in icing conditions. Therefore, the Safety Board believes that the FAA should require principal operations inspectors (POIs) to discuss the information contained in AFM revisions and/or manufacturers' OBs with affected air carrier operators and, if the POI determines that the information contained in those publications is important information for flight operations, to encourage the affected air carrier operators to share that information with the pilots who are operating those airplanes.

According to EMB-120 pilots from Comair and the Air Line Pilots Association (ALPA), their discussions with other EMB-120 flightcrews indicate that the procedural change is still a controversial issue, despite the information revealed during this accident investigation and at the November 1997 Airplane Deicing Boot Ice Bridging Workshop. This illustrates how thoroughly ingrained the ice bridging concept was in pilots and operators and the importance of an ice bridging pilot education program. Therefore, a thin, yet performance-decreasing type of ice (similar to that likely accumulated by Comair flight 3272) can present a more hazardous situation than a 3-inch ram's horn ice accumulation because it would not necessarily prompt the activation of the boots. Based on this information, the Safety Board concludes that the current operating procedures recommending that pilots wait until ice accumulates to an observable thickness before activating leading edge deicing boots results in unnecessary exposure to a significant risk for turbopropeller-driven airplane flight operations. Based primarily on concerns about ice bridging, pilots continue to use procedures and practices that increase the likelihood of (potentially hazardous) degraded airplane performance resulting from small amounts of rough ice accumulated on the leading edges.

The Safety Board is aware that the FAA, NASA, and ALPA plan to organize an industry-wide air carrier pilot training campaign to increase pilots' understanding of the ice bridging phenomenon and safe operation of deicing boots. Unfortunately, according to NASA personnel, the training program has not yet begun because the FAA is still developing its position based on information from the Ice Bridging Workshop. The Safety Board appreciates the FAA's intention to initiate the development of ice bridging training and its desire to ensure that the training is as thorough and accurate as possible; however, the Board is concerned that the planned training is being delayed. Further, the planned training primarily targets air carrier pilots, and the Board considers it important that the information be disseminated to all affected pilots/operators. The Safety Board is concerned that if nonair carrier pilots and operators do not receive the training, they may operate turbopropeller-driven airplanes in icing conditions using deicing boot procedures that result in less safe flight operations. A training program that reaches only a limited part of the pilot population may not be sufficient to eliminate the pervasive beliefs regarding the potential for ice bridging in turbopropeller-driven airplanes.

Therefore, the Safety Board believes that the FAA should (with NASA and other interested aviation organizations) organize and implement an industry-wide training effort to educate manufacturers, operators, and pilots of air carrier and general aviation turbopropeller-driven airplanes regarding the hazards of thin, possibly imperceptible, rough ice accumulations, the importance of activating the leading edge deicing boots as soon as the airplane enters icing conditions (for those airplanes in which ice bridging is not a concern), and the importance of maintaining minimum airspeeds in icing conditions. The Safety Board encourages the FAA and NASA to expedite this training effort. Further, because ice bridging is not a concern in modern turbopropeller-driven airplanes and because thin amounts of rough ice can be extremely hazardous, the Safety Board believes that the FAA should require manufacturers and operators of modern turbopropeller-driven airplanes in which ice bridging is not a concern to review and revise the guidance contained in their manuals and training programs to include updated icing information and to emphasize that leading edge deicing boots should be activated as soon as the airplane enters icing conditions.

It is important to note that although leading edge deicing boots are useful in minimizing the adverse affects of ice accumulation on an airplane's protected surfaces, activation of deicing boots does not result in a completely clean boot surface; some residual ice remains on the deicing boot after it cycles, and intercycle ice accumulates between deicing boot cycles (on the EMB-120, during the 54-second or 174-second intervals, depending on the mode of boot operation selected). Icing tunnel tests indicate that when the deicing boots are activated early, the initial deicing boot cycle leaves a higher percentage of residual ice than it would with delayed deicing boot activation. However, when the deicing boots remained operating during the remainder of the ice encounter, subsequent deicing boot cycles resulted in a wing leading edge about as clean as would occur with delayed boot activation.

The FAA/UIUC wind tunnel tests revealed that even a thin, sparse (5 percent to 10 percent density ice coverage) amount of rough ice accumulation over the leading edge deicing boot coverage area resulted in significant aerodynamic degradation. This information raises questions about the effectiveness of leading edge deicing boots when dealing with this type of ice accumulation, especially considering a B.F. Goodrich estimation that a good, effective deicing boot shed leaves about 20 percent of the accumulated ice on the boots. The sparse ice coverage observed during the first 30 to 60 seconds of exposure time in some of NASA's icing tunnel test conditions (and which could occur between deicing boot cycles) was estimated by observers to be about 10 percent. This combined research indicates that it is possible for a hazardous situation to occur even if pilots operate the deicing boots early and throughout the icing encounter. The Westair flight 7233 incident, in which uncommanded roll and pitch excursions occurred despite the fact that the pilots stated that they had activated the leading edge deicing boots and selected the heavy boot operation mode,[15] may be an example of such a hazardous situation.

In addition, a hazardous situation may develop even if deicing boots are operated throughout an icing encounter as a result of ice accretions on an airplane's unprotected surfaces, such as aft of the deicing boots. The B.F. Goodrich impingement study, NASA's LEWICE calculations, and NASA IRT tests indicated that a light accretion may occur on the unprotected lower wing surfaces aft of the deicing boot on the EMB-120. However, Embraer representatives stated that such an ice accretion would result in only a trace of ice accumulating aft of the deicing boots and would have a minimal aerodynamic penalty in drag only. Although there was no evidence of ice accretion aft of the deicing boot during the EMB-120 certification natural icing tests and it was not possible to determine whether the accident airplane's ice accretion extended aft of the deicing boot coverage, it is possible that ice accretion on the unprotected surface aft of the deicing boot could exacerbate a potentially hazardous icing situation.

Based on icing and wind tunnel research and information from the Westair incident, the Safety Board concludes that it is possible that ice accretion on unprotected surfaces and intercycle ice accretions on protected surfaces can significantly and adversely affect the aerodynamic performance of an airplane even when leading edge deicing boots are activated and operating normally. Thus, pilots can minimize (but not always prevent) the adverse effects of ice accumulation on the airplane's leading edges by activating the leading edge deicing boots at the first sign of ice accretion. It is not clear what effect residual ice/ice accretions on unprotected nonleading edge airframe surfaces have on flight handling characteristics. Because not enough is known or understood about icing in general, and especially about the effects of intercycle and residual ice, the Safety Board believes that the FAA should (with NASA and other interested aviation organizations) conduct additional research to identify realistic ice accumulations, to include intercycle and residual ice accumulations and ice accumulations on unprotected surfaces aft of the deicing boots, and to determine the effects and criticality of such ice accumulations; further, the information developed through such research should be incorporated into aircraft certification requirements and pilot training programs at all levels.

The Safety Board considers it likely that future ice detection/protection systems will decrease the hazards associated with icing by incorporating ice detection and protection (automatic activation of deicing boots or anti-icing systems) for individual surfaces, including the horizontal stabilizers, of all airplanes certificated for flight in icing conditions. However, because ice accretions and their effects are not yet fully understood, the Safety Board concludes that

[15] According to the pilots of Westair flight 7233, they were aware that they were operating in "icing conditions;" they stated that they observed ice accumulating on the airplane and had activated the leading edge deicing boots when the airplane entered the clouds during their departure.

current ice detection/protection requirements and application of technology (particularly deice boots) may not provide adequate protection for a variety of ice accumulation scenarios (tailplane, SLD, thin, rough ice accumulations, etc.). Therefore, the Safety Board believes that the FAA should actively pursue research with airframe manufacturers and other industry personnel to develop effective ice detection/protection systems that will keep critical airplane surfaces free of ice; then, require their installation on newly manufactured and in-service airplanes certificated for flight in icing conditions.

Comair's Airspeed Guidance

During postaccident interviews, some of Comair's pilot training personnel indicated that the company's EMB-120 pilot training emphasized the 160-knot minimum airspeed for operating in icing conditions, and Comair's EMB-120 Program Manager told Safety Board investigators that 170 knots is the only airspeed the company supports for operating with the landing gear and flaps retracted. Although the Safety Board's review of the airspeed guidance contained in Comair's EMB-120 FSM revealed that it did not contain specific minimum maneuvering airspeeds for flight in icing conditions and for various airplane configurations, it did contain general airspeed information in descriptions of normal and non-normal procedures and maneuvers. For example, the technique outlined in Comair's FSM for an instrument landing system (ILS) approach associated the base leg vector position (which was the accident airplane's approximate position on the approach before the upset, albeit still about 20 miles from the destination airport) with 170 knots and the flaps 15 configuration. Additional guidance for the ILS approach procedure associated 150 knots airspeed with the selection of 25° of flaps. (This guidance did not constitute minimum airspeed guidance, but it did represent how Comair intended the airplane to be flown and configured on an ILS approach.)

Comair's EMB-120 airspeed reference cards (readily available and used by the flightcrew in the cockpit) addressed a reference airspeed at an airplane gross weight of 24,000 pounds with gear and flaps retracted ($V_{ref}0$) of 147 knots, and a final segment airspeed (V_{fs})[16] of 143 knots (airspeeds varied, depending on the airplane's gross landing weight and temperatures). Comair's EMB-120 FSM addressed $V_{ref}0$ and V_{fs} airspeeds consistent with the cockpit airspeed reference cards. The FSM also contained guidance for a no-flaps approach and landing (a non-normal procedure) that specified a minimum airspeed of 160 knots while maneuvering on the approach, with a slight airspeed reduction (the amount varying with the weight of the airplane) once established on final approach. Further, the flap control fault (a non-normal procedure) checklist procedure advised pilots to add 35 knots to the reference airspeed for 45° of flaps for the zero flaps configuration, resulting in airspeeds between 140 and 150 knots (again depending on the airplane's gross weight). The published stall airspeed for the EMB-120 at 24,000 pounds gross weight with landing gear and flaps retracted was 114 knots.

During the 13 months before the accident, Comair had issued an interoffice memorandum and an FSB that contained guidance advising EMB-120 pilots to maintain higher airspeeds than

---

[16] V_{fs} is the target airspeed for flap retraction after takeoff or during go-around.

normal when operating in icing conditions. The Comair interoffice memo, issued on December 8, 1995, advised pilots not to operate the EMB-120 at less than 160 knots in icing conditions and to use 170 knots for holding in icing conditions. According to Comair, this memo was distributed to all EMB-120 pilots through their company mailboxes and a 30-day pilot-read binder but was not incorporated into an FSB or a revision to the Comair EMB-120 FSM. The FSB, issued on October 18, 1996 (to be inserted at the back of the FSM), advised pilots to maintain a minimum airspeed of 170 knots when climbing on autopilot or holding in icing conditions, with no mention of a minimum airspeed for non-climbing/non-holding icing operations. Comair's October 1996 FSB did not support or repeat the interoffice memo's blanket 160-knot minimum airspeed for operating an EMB-120 in icing conditions. The Safety Board notes that the language used, the different airspeeds and criteria contained in the guidance, Comair's methods of distribution, and the company's failure to incorporate the guidance as a formal, permanent revision to the FSM might have caused pilots to be uncertain of the appropriate airspeeds for their circumstances.

Additional preaccident airspeed guidance was contained on the same page as revision 43 to Embraer's EMB-120 AFM (issued in April 1996), which stated that the manufacturer's recommended minimum airspeed for the EMB-120 in icing conditions with landing gear and flaps retracted was 160 knots. However, at the time of the accident, Comair had not incorporated the AFM revision 43 information into its EMB-120 FSM. Further, Comair had not incorporated long-standing AFM information into its FAA-approved EMB-120 FSM; specifically, Comair's FSM did not contain the note advising pilots to increase their approach airspeeds by 5 to 10 knots in icing conditions. (The Safety Board notes that this guidance had been included in Embraer's EMB-120 AFM at least since August 1991, and Comair's FAA POI had not required the company to incorporate the icing-related airspeed guidance into its FSM.) Because Comair's pilots used the company's Operations Manual and FSM as their primary sources of procedural guidance (rather than the EMB-120 AFM), it is likely that many Comair pilots were not aware that Embraer considered 160 knots to be the minimum airspeed for operating the EMB-120 in icing conditions. This is supported by the variations in the responses provided during postaccident interviews by the 16 Comair EMB-120 pilots (including line pilots, flight instructors, and line check airmen) when they were asked about the minimum airspeed for operating the EMB-120 without flaps extended in icing conditions.

Several of the pilots interviewed stated that they would not have been comfortable operating an EMB-120 in icing conditions at an airspeed of 150 knots without flaps extended, citing 160 knots or 170 knots as more acceptable airspeeds, based on previous bulletins and memos.[17] Other pilots indicated that there was no operational requirement to maintain a higher airspeed in icing conditions but cited a note in Comair's FSM that advised pilots to increase approach airspeeds by 5 to 10 knots when operating in icing conditions. However, three Comair EMB-120 pilots made no special reference to icing conditions and told investigators that the minimum operating airspeed for the EMB-120 flaps up was below 150 knots. One Comair EMB-120 captain stated that he considered the absolute minimum airspeed for operating the airplane

[17] Although many of Comair's line pilots, flight instructors, and line check airmen appeared uncertain of the minimum airspeed for operating an EMB-120 in icing conditions without landing gear or flaps extended, most of the pilots interviewed were aware that Comair's FSB 96-04 stated that the minimum airspeed for holding in icing conditions was 170 knots.

without flaps [in nonicing conditions] to be the V_{fs} airspeed; a Comair EMB-120 flight instructor cited a minimum EMB-120 maneuvering airspeed without flaps of 140 knots; and an EMB-120 line check airman stated that "the airplane should fly safely at 150 knots clean, but this is not a practice [we] advocate....V_{fs} (141 knots to 147 knots), those are the minimum clean speeds."

Thus, although Comair's pilot training personnel indicated that the company's EMB-120 pilot training emphasized the 160-knot minimum airspeed for operating in icing conditions, the varied responses received from EMB-120 pilots during postaccident interviews indicate that the guidance provided was not consistently understood by Comair's pilots. Based on the inconsistencies in the answers provided by Comair pilots during the postaccident interviews and the complex and varied minimum airspeed requirements established by Comair for both icing and nonicing conditions, the Safety Board concludes that the guidance provided by Comair in its memos, bulletins, manuals, and training program did not adequately communicate or emphasize specific minimum airspeeds for operating the EMB-120 in the flaps-up configuration, in or out of icing conditions, and thus contributed to the accident.

Flightcrew's Airspeed/Configuration Decisions and Actions

The Safety Board's review of the flightcrew's actions revealed that there was no pilot discussion of flap usage, stall speeds, recommended minimum airspeeds for icing conditions, ice accumulation (potential or observed) and its effects on the airplane's performance at any time during the descent from cruise altitude, nor was there any requirement for such discussion. The Safety Board considers it likely that the pilots would have commented and/or taken action (such as activating the deicing boots and/or extending the flaps) if they had perceived an unsafe condition, either as the result of a significant ice accumulation or an unsafe airspeed assignment for the airplane's configuration. The Safety Board acknowledges that increasing the airspeed by some increment (V_{ref} + 5 knots according to Comair's EMB-120 FSM) when ice accretion is observed is a fairly standard adjustment in the aviation industry, and Comair's FSB 96-04 specified a minimum airspeed of 170 knots for holding in icing conditions. However, ATC had not issued holding instructions to the pilots of Comair flight 3272, nor had ATC indicated that the pilots should expect to receive holding instructions during the approach to DTW. Therefore, the pilots might not have considered the 170-knot minimum airspeed for holding in icing conditions. Additionally, as previously discussed, the pilots might not have recognized that they were operating in icing conditions because it is possible that the accident airplane accreted a thin, rough layer of glaze ice that was imperceptible to the pilots. Because there were no comments recorded by the CVR and because the pilots accepted the 150-knot airspeed assignment without hesitation, comment, or reconfiguration, the Safety Board concludes that the pilots likely did not recognize the need to abide by special restrictions on airspeeds that were established for icing conditions because they did not perceive the significance (or presence) of Comair flight 3272's ice accumulation. Further, based on the uncertainty regarding minimum airspeeds exhibited by Comair pilots during postaccident interviews, the Safety Board considers it likely that under conditions similar to those encountered by the pilots of Comair flight 3272, other Comair pilots might have accepted the same 150-knot airspeed assignment.

Although the Safety Board considers Comair's airspeed guidance ambiguous and unclear and acknowledges that the flightcrew might not have perceived that the airplane was accumulating ice that affected its flight handling characteristics, the Safety Board notes that the preponderance of the airspeed guidance available to the pilots indicated that EMB-120 operating airspeeds of 160 or 170 knots were standard for operating without flaps extended under any (icing or nonicing) conditions. Although these airspeeds were not established minimum airspeeds, they were the operator's procedural guidance and the standards to which Comair's pilots were trained. The Safety Board considers that any pilot deviations from standard procedures during flight operations (although not prohibited and not necessarily unsafe) should be accomplished thoughtfully and with full consideration given to the possible risks involved. In this case, operating at 150 knots provided the pilots with a reduced safety margin above the airplane's stall speed. The reduction in stall margin was especially critical to the accident flight because the accident airplane had accreted structural ice during its descent, which was having an adverse effect on the airplane's performance characteristics. The Safety Board notes that the pilots could have increased the stall margin by extending 15° of flaps and still complied with ATC's airspeed assignment. Further, there was no safety or operational reason to avoid extending the flaps.[18]

The Safety Board considers it critical that pilots take into consideration potential adverse conditions, and make correspondingly conservative decisions where they are warranted. Although the pilots might not have perceived that the airplane was accumulating any ice, their activation of the propeller and windshield heat when the airplane entered icing conditions was an indication that they were aware that they were entering conditions in which ice accumulation was possible.

Based on Comair's guidance for an ILS approach (which Comair uses during pilot training) that associates 170 knots with 15° of flaps on the base leg position, and additional airspeed guidance suggesting airspeeds of 160 to 170 knots for the accident flight's conditions, and the pilots' responsibility to make safe, conservative decisions consistent with flight in icing conditions, the Safety Board concludes that whether the pilots perceived ice accumulating on the airplane or not, they should have recognized that operating in icing conditions at the ATC-assigned airspeed of 150 knots with flaps retracted could result in an unsafe flight situation; therefore, their acceptance of the 150-knot airspeed assignment in icing conditions without extending flaps contributed to the accident.

---

[18] The Safety Board considered the possibility that the flightcrew avoided extending the flaps because of guidance to avoid extended operations in icing conditions with flaps extended. However, as previously discussed, there were numerous indications that the flightcrew was not considering icing as a significant factor in the airplane's operation at the time. The Safety Board also considered that the pilots might have believed that they had already extended the flaps to 15° at the time that they accepted the 150 knot ATC-assigned airspeed. However, at that time, the airplane was about 20 miles from the destination airport and maintaining an assigned airspeed of 190 knots; thus, the pilots had not received any of the usual (distance and airspeed-related) cues to extend the flaps. The Safety Board was unable to determine whether the pilots believed they had extended the flaps at any subsequent time.

FAA-related Information Regarding Minimum Airspeeds

Because the issue of safe minimum airspeeds is complex and critical to safe flight operations, in May 1997 the Safety Board issued Safety Recommendation A-97-31, which asked the FAA to require air carriers to reflect FAA-approved minimum airspeeds for all flap settings and phases of flight, including flight in icing conditions, in their EMB-120 operating manuals. The Safety Board's recommendation letter referenced the FAA's notice of proposed rulemaking (NPRM) 97-NM-46-AD, which established a minimum safe EMB-120 airspeed in icing conditions of 160 knots based on initial icing certification flight test data, stating the following, in part:

> The NPRM addresses many of the safety issues discussed in this letter. The Safety Board is evaluating whether the proposed 160 KIAS [knots indicated airspeed] minimum airspeed in icing conditions is appropriate, and if the single speed adequately addresses the intent of what would have been our first recommendation: that is, for the FAA to approve for inclusion in Embraer's EMB-120 airplane flight manual minimum airspeeds for all flap settings and phases of flight, including flight in icing conditions.

The Safety Board reiterated its concerns on this subject in its response to the FAA's NPRM 97-NM-46-AD. Despite the Board's concerns, the FAA's final rulemaking for airworthiness directive (AD) 97-26-06 indicated that Embraer's initial icing certification flight tests demonstrated that a minimum airspeed of 160 knots provided an adequate stall margin, "provided the ice protection systems are properly activated." Currently, the FAA-required minimum EMB-120 airspeed guidance consists of 160 knots minimum airspeed for operating in icing conditions.

AD 97-26-06 did not satisfactorily address the concerns that were expressed by the Safety Board in its communications regarding Safety Recommendation A-97-31 and in its response to the NPRM because the 160-knot airspeed was not scientifically determined and does not ensure an acceptable safety margin for all foreseeable flight conditions (evidence of Comair flight 3272's loss of control were apparent at 156 knots—with a slightly different ice accumulation scenario, the loss of control might have occurred earlier in the event) and because the FAA's response did not adequately address the complicated issue of the minimum operating airspeeds (at various flap settings) for the EMB-120 in icing conditions. The Safety Board notes that after this accident, because Comair management did not believe that a 160-knot airspeed ensured adequate stall margin, the company established a minimum airspeed of 170 knots for operating the EMB-120 in icing conditions, thus increasing the stall margin in icing conditions beyond that required by the FAA. The Safety Board is concerned that absent the scientifically determined airspeed guidance it requested from the FAA, some operators are arbitrarily electing to increase their minimum EMB-120 airspeeds, whereas others may continue to follow current FAA guidance that provides an inadequate safety margin. Although an airspeed greater than 160 knots should be required to provide an adequate safety margin, without a scientifically based determination of minimum operating airspeed in icing conditions, some operators may increase the airspeed too much, increasing the risk of tailplane stall.

The Safety Board is aware that manufacturers and operators of many large air transport airplanes have published minimum airspeeds associated with various flap configurations and phases and conditions of flight. These airspeeds are incorporated into operator's manuals and pilot training programs and are helpful for pilots of these airplanes during flight operations. The Safety Board again concludes that minimum airspeed information for various flap configurations and phases and conditions of flight would be helpful to pilots of all passenger-carrying airplanes. Therefore, the Safety Board believes that the FAA should require manufacturers of all turbine-engine driven airplanes (including the EMB-120) to provide minimum maneuvering airspeed information for all airplane configurations, phases, and conditions of flight (icing and nonicing conditions); minimum airspeeds also should take into consideration the effects of various types, amounts, and locations of ice accumulation, including thin amounts of very rough ice, ice accumulated in SLD icing conditions, and tailplane icing.

The circumstances of the Westair incident indicate that despite the increased availability of icing-related information since the Comair accident, the increase in icing-related regulations and the heightened awareness of the hazards of structural icing among the operator/pilot population that has resulted from recent icing-related aviation accidents, some EMB-120 pilots remain less vigilant to decreases in airspeed than is prudent. Although EMB-120 pilots have more icing-related information available to them now than they did before the Comair flight 3272 accident, adequate guidance has still not been provided on minimum operating airspeeds and the hazards of various types and amounts (sometimes imperceptible) of ice accumulation. Therefore, the Safety Board believes that the FAA should require the operators of all turbine-engine driven airplanes (including the EMB-120) to incorporate the manufacturer's minimum maneuvering airspeeds for various airplane configurations and phases and conditions of flight in their operating manuals and pilot training programs in a clear and concise manner, with emphasis on maintaining minimum safe airspeeds while operating in icing conditions.

Stall Warning/Protection System

The stall warning systems that are required by 14 CFR Part 25 are intended to provide flightcrews with adequate warning of proximity to the stall AOA; however, they often do not provide adequate warning when the airplane is operating in icing conditions in which the stall AOA is markedly reduced. This was the case in this accident; the airplane had departed from controlled flight before activation of the stick shaker.

The accident airplane's stall warning/protection system used information from the sideslip sensor and the right and left AOA sensors to determine an approaching aerodynamic stall condition. Under normal conditions, with uncontaminated airfoils and the airplane operating with the landing gear and flaps retracted, EMB-120 stick shaker activation would occur at 10° and the AOA at which the airplane actually stalled would be 18°, providing a margin of about 8°. However, with the wings contaminated, the airflow over the upper wing surface is disrupted, the stall airspeed is increased, and the stall AOA is reduced,[19] thus decreasing the margin between

[19] FAA and NASA wind/icing tunnel data indicate that the NACA 23012 airfoil with a thin layer of rough ice on the leading edge with a small ice ridge can stall at angles of attack as low as 5° or 6°.

stall warning and actual stall. The decreased margin can result in a contaminated airplane stalling with little or no prestall warning (i.e., the stick shaker) provided to the pilots and at a higher airspeed and lower AOA than a pilot might expect. Further, if a pilot was confident that the airplane's stall warning/protection system would provide an adequate stall warning margin, that pilot may not be overly concerned about the flight conditions at that time.

The Safety Board notes that the stall warning system installed on the Avions de Transport Regional (ATR) 42/72 decreases the critical AOA for aural alert and stick shaker from 12.5° to 7.5° when the anti-icing system is activated. The 7.5° AOA threshold was selected by ATR to account for a reduced stall AOA with an ice accumulation. In addition, the Safety Board is aware that stall warning/protection systems exist that incorporate airflow sensors into their logic and adjust the stick shaker/pusher activation to compensate for the disruptions in airflow that result from ice accumulation on the airfoil.

Because the accident airplane's FDR and CVR data indicated that the autopilot disengaged and the roll upset occurred before the stick shaker activated, the Safety Board concludes that the stall warning system installed in the accident airplane did not provide an adequate warning to the pilots because ice contamination was present on the airplane's airfoils and the system was not designed to account for aerodynamic degradation or adjust its warning to compensate for the reduced stall warning margin caused by the ice. Thus, the Safety Board believes that the FAA should require the manufacturers and operators of all airplanes that are certificated to operate in icing conditions to install stall warning/protection systems that provide a cockpit warning (aural warning and/or stick shaker) before the onset of stall when the airplane is operating in icing conditions.

Operation of the Autopilot

The Safety Board was unable to positively determine whether the autopilot was operating properly based on physical evidence (impact damage precluded functional tests). However, based on FDR data and a review of the autopilot design characteristics, the Safety Board concludes that the accident airplane's autopilot was capable of normal operation and appeared to be operating normally during the last minutes of the accident flight, and the autopilot disconnect and warning systems operated in a manner consistent with their design logic.

The Safety Board evaluated the flightcrew's use of the autopilot as it affected the cues presented to the pilots about the impending loss of control and the behavior of the ailerons as the loss of control developed. The autopilot's actions during the last seconds before it disengaged provided some visual cues that could have warned the pilots of the airplane's performance degradation. For example, during the 15 seconds before the autopilot disengaged, it moved the control wheel to command the ailerons to move in a RWD direction while the flight instruments and the pilots' heading selection indicated that the airplane was in a left bank. Although it would have been possible for the pilots to observe this and deduce that an anomalous flight condition existed, these visual cues began very gradually and were subtle and short lived. The control wheel did not move more than 10°, and the roll angle did not exceed 30° (only slightly greater than the normal autopilot bank limit for the selected left turn), until about 8 seconds before the upset.

The deviations from the desired airplane attitude were becoming noticeable about the time that the pilots were increasing engine power to maintain 150 knots and continued as the captain directed the first officer's attention to the airplane's airspeed (about 5 seconds before the upset). Given this distraction, it is likely that the subtle visual cues that were available were not adequate to prompt the pilots to take the direct and aggressive action that would have been necessary to avoid the upset.

If at least one of the pilots had been manually monitoring the airplane's (autopilot's) performance by maintaining a light grip on the control wheel, it is more likely that the autopilot-commanded right control wheel application (control wheel movement in the opposite direction to the turn) would have been noticed at some point before the autopilot disengaged. However, the pilots could not have identified the buildup in control wheel forces that would have preceded and accompanied the RWD control wheel movements unless the autopilot had been disengaged and they were flying the airplane manually.

Postaccident simulator tests indicated that throughout most of the airplane's left roll, even up to the time the autopilot disengaged, the pilots could have prevented the loss of control of the airplane by decreasing the AOA. However, when the autopilot suddenly disengaged, the release of the autopilot's RWD control input allowed the ailerons to move rapidly in the left wing down direction, which caused the airplane to immediately roll to a nearly inverted attitude.

The sudden disengagement of the autopilot with no warning to the flightcrew is an essential difference between the Comair flight 3272 accident and the Westair flight 7233 incident (other differences include the following: according to their statements, the Westair pilots had activated the leading edge deicing boots, and the Westair airplane's airspeed was below its target airspeed for about 3½ minutes, whereas Comair's airspeed was below the target airspeed for 10 seconds). The Westair pilots intentionally disengaged the autopilot and resumed flying the airplane manually when they felt the airplane shudder or rumble, before an unusual attitude developed. Although the Westair pilots subsequently experienced several roll oscillations and deviated 600 feet below their assigned altitude before they extended 15° of flaps, they were able to regain control of the airplane. Comair flight 3272's autopilot automatically disengaged, and, because of the left roll tendency, the airplane rolled left to a nearly inverted attitude almost immediately after the autopilot disengaged—before the pilots had their hands on the controls. The Westair airplane remained moderately more controllable because the pilots had their hands on the control wheel and were manually flying the airplane as soon as the autopilot was disengaged; further, the excessive roll oscillations did not begin until about 4 seconds after the autopilot disengaged. It is likely that the Comair flight 3272 upset event would have been more controllable if the Comair pilots had recognized the airplane's degraded aerodynamic condition and disengaged the autopilot to fly the airplane manually before the autopilot disengaged automatically and unexpectedly. The Safety Board concludes that, had the pilots been flying the airplane manually (without the autopilot engaged), they likely would have noted the increased RWD control wheel force needed to maintain the desired left bank, become aware of the airplane's altered performance characteristics, and increased their airspeed or otherwise altered their flight situation to avoid the loss of control.

After the ATR-72 accident near Roselawn, Indiana, the Safety Board issued Urgent Safety Recommendation A-94-184 to the FAA recommending, in part, that it prohibit ATR-42/72 pilots from using the autopilot in icing conditions because of the autopilot's ability to mask the airplane's changing flight condition. The FAA's response prohibited ATR 42/72 pilots from using the autopilot in icing conditions unless specific modifications were accomplished or alternative procedures and training were adopted, and the Safety Board reclassified Safety Recommendation A-94-184 "Closed—Acceptable Action." Further, based on the FAA's AD 96-09-24, in the summer of 1996, Comair revised its manuals (based on Embraer changes) to indicate that because "the autopilot may mask cues that indicate adverse changes in handling characteristics, use of the autopilot is prohibited" in SLD icing conditions.

However, the circumstances of the Comair accident demonstrate that restricting use of the autopilot only when the airplane is operating in SLD icing conditions may not be adequate. Moreover, an airplane may encounter a hazardous flight condition from use of the autopilot in icing conditions that may not be perceptible to the flightcrew. Case histories indicate that relying on pilots to activate deicing boot systems or maintain minimum airspeeds in icing conditions does not ensure safe operation of an airplane in icing conditions; pilots may not always be attentive enough to airspeeds, they may not recognize the onset of ice accumulation to trigger deicing boot activation, or deicing boot activation may not be sufficient to prevent icing-related flight control anomalies in some conditions because of intercycle icing. However, if the pilots of Comair flight 3272 had intentionally disengaged the autopilot upon the onset of ice accretion, the autopilot would not have masked the tactile cues to the airplane's aerodynamic degradation, nor would the autopilot have automatically disengaged at a subsequent, more critical time. Thus, the pilots would not have initiated their recovery from an extremely unusual attitude.

The Safety Board considered whether operation of the autopilot in the "[½ bank] angle" mode, as recommended in the "Descent/Holding/Landing" section of Embraer's OB No. 120-002/96, "Operation in Icing Conditions," might provide an adequate level of safety for use of the autopilot during maneuvering flight in icing conditions. The Safety Board notes that the sideslip and severe asymmetric degradation of the accident airplane appeared not to have begun (based on FDR data) until the airplane reached 20° of left bank (at 1554:10). However, the Safety Board also notes that the autopilot's ½ bank angle mode only applies to the lateral control mode in which it is selected—when the autopilot lateral control mode changes during flight (either pilot-commanded, or pilot preselected, such as during the transition from heading mode to approach mode), the autopilot reverts to commanding standard bank angles. Thus, the pilot would need to reengage the ½ bank angle mode in the new lateral control mode, if ½ bank angle mode is desired. This would result in an increased pilot workload during the approach phase of flight (already a high workload phase of flight) or the task (reengaging ½ bank angle mode) might not be accomplished. Thus, the Safety Board considers it unlikely that the use of the autopilot's ½ bank angle mode while operating in icing conditions (as recommended in Embraer's OB 120-002/96) would ensure an adequate level of safety to EMB-120 pilots operating in conditions conducive to the formation of structural ice.

Therefore, the Safety Board concludes that disengagement of the autopilot during all operations in icing conditions is necessary to enable pilots to sense the aerodynamic effects of icing and enhance their ability to retain control of the airplane. Because there is no reason to believe that these circumstances may be confined to the ATR-72 and the EMB-120, the Safety Board believes that the FAA should require all operators of turbopropeller-driven air carrier airplanes to require pilots to disengage the autopilot and fly the airplane manually when they activate the anti-ice systems.

Further, based on this accident and other air carrier incidents (such as the Evergreen International B-747), the Safety Board has considered the feasibility and value of a cockpit warning when an airplane first exceeds the autopilot's maximum bank and/or pitch command limits to alert pilots to an anomalous situation. According to AlliedSignal personnel, it is possible to adjust their recent model ground proximity warning systems (GPWS) to provide a cockpit bank angle warning when the airplane's bank angle exceeds the autopilot's normal command limit with the autopilot activated. The Safety Board concludes that if the pilots of Comair flight 3272 had received a GPWS, autopilot, or other system-generated cockpit warning when the airplane first exceeded the autopilot's maximum bank command limits with the autopilot activated, they might have been able to avoid the unusual attitude condition that resulted from the autopilot's sudden disengagement. Therefore, the Safety Board believes that the FAA should require all manufacturers of transport-category airplanes to incorporate logic into all new and existing transport-category airplanes that have autopilots installed to provide a cockpit aural warning to alert pilots when the airplane's bank and/or pitch exceeds the autopilot's maximum bank and/or pitch command limits.

FAA Continuing Airworthiness Oversight Issues

The Safety Board notes that, like the ATR-42 and -72, the EMB-120 exhibited a history of icing-related upsets/losses of control before being involved in a related fatal accident. At the time of the Comair accident, six icing-related EMB-120 events had been documented, the first of which occurred in June 1989.[20] The Safety Board's review of these incidents shows that before the Comair accident, the EMB-120 fleet had experienced repeated instances of roll upsets associated with ice accumulations that the pilots either did not observe or did not consider sufficient to prompt activation of the deicing boots.

FAA and Embraer personnel had noted the recurring events, and the FAA presented a summary of the six events at an FAA/industry meeting (attended by Safety Board staff) on November 7, 1995. Further, the FAA and Embraer discussed the events with representatives from Comair and other operators at a meeting on November 15, 1995, and additional discussion took place during the EMB-120 SLD icing tanker tests in December 1995. An FAA engineer reviewed these six incidents in a draft report dated January 26, 1996.

The Safety Board has been unable to obtain information about the specific disposition of the draft report within the FAA, although the FAA asserted after the accident that this report did not reflect the official views of the FAA. Nevertheless, the Safety Board notes that more than

[20] Similarly, before the ATR-72 accident at Roselawn, Indiana, the FAA had been aware of a number of prior ATR upset events. The FAA had concluded that these incidents were essentially pilot-induced stall events; however, further investigation revealed that there were more complex airplane controllability issues involved in the ATR upset events.

1 year before the accident, at least some members of the FAA certification staff responsible for handling EMB-120 icing issues were concerned about, and were considering recommendations on, the following issues: 1) the airplane's roll behavior with ice accretion, 2) high drag from ice accretions that are not considered by the flightcrew to warrant activating the deicing boots, 3) inadequate stall warning in icing conditions, 4) inadequate stall margin with the airspeed established for use in icing conditions, and 5) problems stemming from the use of the autopilot in these conditions.

The FAA's official response to the six preaccident EMB-120 icing-related events, as expressed to the Safety Board by aircraft certification office (ACO) personnel, was that these incidents shared a common factor—flightcrew failure to activate the leading edge deicing boots. The FAA apparently believed that the EMB-120 was safe to operate in icing conditions as long as the boots were operated.

Hence, the FAA's primary action regarding EMB-120 icing before the accident was to approve the Embraer-proposed, CTA-approved revision to the AFM that pilots activate the boots at the first indication of ice accumulation (revision 43). In doing so, the FAA ACO apparently did not accept the draft report's conclusions, which recognized that pilots would not activate the boots if they did not recognize ice accumulation, that an engaged autopilot masked the tactile cues of icing, and that under these conditions, the flightcrew also could be deprived of an adequate stall warning.

The Safety Board notes with disappointment that this was the latest in a series of limited actions taken by the FAA to address the problems of structural icing in transport airplane certification and operation. Basic knowledge about the aerodynamics of icing (including the knowledge regarding the hazards of small amounts of surface roughness/ice) has been well established for the past 50 years, and there is nothing that has been learned in the most recent, postaccident wind tunnel tests and analyses that could not have been learned before this Comair accident.

Many of the concerns raised about icing in this investigation were previously identified by the Safety Board as early as its September 1981 study on icing avoidance and protection. The study raised concerns about the adequacy of the Part 25 appendix C envelope and icing certification and the difficulties in defining and forecasting icing conditions; as a result of the study, the Safety Board recommended, in part, that the FAA evaluate individual aircraft performance in icing conditions and establish operational limits, review icing criteria in Part 25 and expand (adjust) the Part 25 appendix C envelope as necessary, and establish standardized procedures for icing certification. For many years, the FAA did not respond positively to the Safety Board's recommendations, indicating that icing was not a significant problem for airplanes certificated under Part 25 appendix C. However, subsequent icing-related accidents at Pasco, Washington (in December 1989), and Beckley, West Virginia (in January 1991), revealed that flight control anomalies could result from tailplane icing and an icing-related accident at Cleveland, Ohio (in February 1991), revealed that slightly rough ice accumulations on the wing upper surface can result in hazardous flight handling characteristics.[21] Further, the October 1994 ATR-72 accident at Roselawn, Indiana, demonstrated that icing outside the Part 25 appendix C envelope could be a significant problem for airplanes certificated to operate in icing conditions.

After this series of fatal accidents (all of which involved icing in transport airplanes operated in air carrier service) drew attention to icing-related hazards, the FAA reacted incrementally to tailplane icing, then rough ice accumulations on the upper wing, and then, later, to runback icing (SLD). The Safety Board recognizes that following the Comair flight 3272 accident, the FAA began an important icing-related research program with Embraer and the UIUC. This work has resulted in findings about the effects of thin/rough ice accretions and ice ridges on boots, with other possible factors (such as intercycle icing and residual ice on boots) as yet unknown or unresolved. However, had the FAA adequately responded to the Safety Board's 1981 icing recommendation, the earlier accidents, or the concerns expressed in its own staff's draft report on the EMB-120 and conducted a thorough program of icing-related research that defined a course of action to prevent similar incidents by addressing the certification and operational issues (autopilot use in icing conditions, no autopilot bank angle exceedence warning, no stall warning/protection system adjustment for icing conditions, the effects of thin, rough ice and SLD accretions, etc.), this accident would likely have been avoided.

The Safety Board notes that the failure of the FAA to promptly and systematically address these certification and operational issues resulted in the pilots of Comair flight 3272 being in a situation in which they lacked sufficient tools (autopilot bank angle warning, adjusted stall warning/protection system, ice detection system, adequate deice procedures) and information (airspeed guidance, hazards of thin rough ice accretions, and absence of ice bridging) to operate safely. The Safety Board concludes that despite the accumulated lessons of several major accidents and (in the case of the EMB-120) the specific findings of a staff engineer, the FAA failed to adopt a systematic and proactive (rather than incremental and reactive) approach to the certification and operational issues of turbopropeller-driven transport airplane icing, which was causal to this accident.

Icing Certification Requirements

The Safety Board reviewed EMB-120 test data from the original certification of the airplane for flight in icing conditions (U.S. and Canadian tests) and the subsequent SLD icing certification tests, which were conducted in 1995 as a result of the ATR-72 accident near Roselawn, Indiana. The Safety Board found no evidence that the EMB-120 did not satisfy the tests to which it was subjected; in fact, during these tests, Embraer demonstrated the airplane's flight handling qualities under conditions that exceeded the boundaries of the Part 25 appendix C envelope in terms of LWC.

---

[21] There have been five DC-9 series 10 airplane takeoff accidents attributed to upper wing ice contamination in the United States since 1968. Although these accidents involved turbojet-driven airplanes (not turbopropeller-driven airplanes, like the other icing-related incidents/accidents discussed in this report), the issue of the FAA's failure to address icing-related operational and certification issues is pertinent to all airplanes certificated for flight in icing conditions.

Despite the apparent fulfillment of all icing certification requirements by the EMB-120, Comair flight 3272 crashed after apparently accreting a thin layer of rough, "sandpaper-type" ice, in icing conditions that likely fell mostly within the boundaries of Part 25 appendix C, although droplets as large as 400 microns might have been present.

Consequently, the Safety Board reviewed the adequacy of the current FAA requirements for the certification of airplanes for flight in icing conditions. For an airplane to be certificated for flight in icing conditions, the FAA requires the manufacturer to demonstrate a limited number of test data points within the Part 25 appendix C envelope. The FAA's icing certification requirements are based on fully functioning and operating anti-icing and deicing systems. Although there is no requirement for manufacturers to consider the effects of delayed activation of ice protection systems, intercycle or residual ice accumulations, or other variables that might result in significant aerodynamic effects, Embraer exceeded the minimum FAA requirements when Embraer tested the EMB-120 with ¾-inch (U.S.) and 1-inch (Canada) ice accretions/shapes during initial icing certification.[22] Certification records indicate that the EMB-120 successfully exhibited satisfactory flight handling characteristics with 3-inch ram's horn ice shapes installed on unprotected surfaces. Further, during the SLD icing controllability tests, the FAA tested the EMB-120 with quarter-round artificial ice shapes as large as 1 inch located at the aft edge of the farthest aft inflatable deicing boot segment (to represent ice accumulated in icing conditions that fall outside the Part 25 appendix C envelope). The airplane exhibited full lateral controllability and satisfactory stall warning characteristics in this condition.[23]

However, Embraer had not demonstrated (nor was the company required by the certification authorities to demonstrate) the EMB-120's performance in other ice configurations that would result from weather conditions within the Part 25 appendix C LWC and droplet size envelope, including realistic ice shapes (or natural ice) representing a thin layer of sandpaper-type ice with a small ice ridge (as may have been experienced by Comair flight 3272). Postaccident icing and wind tunnel information indicated that with a small ice ridge along that thin rough surface, the aerodynamic effect on handling and stall margin/stall warning (reduced stall AOA and rapid decrease in lift) can be worse than any of the ice shapes that the FAA required for icing certification.

The Safety Board's review of data from natural icing flight tests revealed that the airplane's handling characteristics were evaluated with ½-inch accretions on protected surfaces and that the deicing boots' ability to remove ice accretions of up to ½-inch was assessed.

---

[22] For U.S. (FAA) icing certification, the EMB-120 was tested with ¼ inch, ½ inch, and ¾ inch of natural ice on protected surfaces, up to 4 inches of natural ice accumulation on unprotected airfoil surfaces, and 3-inch ram's horn artificial ice shapes on unprotected surfaces; except for the ¾-inch natural ice on protected surfaces, these conditions could be encountered while operating in icing conditions in accordance with procedures outlined in the EMB-120 AFM. However, for Canadian icing certification, the EMB-120 was tested with artificial ice shapes representing conditions considered to be outside normal operation with deicing boots activated (1-inch ram's horn ice shapes on protected surfaces).

[23] Although some control wheel force exceedences were observed, tanker tests identified more realistic ice shapes; during subsequent tests with the realistic ice shapes, no excessive control wheel forces or other anomalies were noted.

Embraer was not required to demonstrate the EMB-120's stall characteristics in adverse operational scenarios, including delayed boot activation, intercycle ice accretion, or residual ice on boots. As a result of the existing icing certification procedures, the FAA did not account for a thin ice accumulation (as was identified during this investigation, and which may not be observed or perceived by pilots to be a threat) that could result in a more hazardous situation than the 3-inch ram's horn shape (which is readily recognizable by pilots as a hazard and would certainly prompt activation of the boots). The Safety Board is concerned that there may be other unaccounted for ice shapes and/or accretion patterns that could result in potentially hazardous performance degradation.

The Safety Board is also concerned that the current icing certification process is overly dependent upon pilot performance; the FAA has long based its icing certification policies and practices on the assumption that pilots will perform their duties without error or misperception. FAA icing-related publications indicate that if ice formations other than those considered in the certification process are present, the airplane's airworthiness may be compromised. After an airplane is certificated by the FAA for flight in appendix C icing conditions, it becomes primarily the pilots' responsibility to ensure that the airplane is operated in icing conditions for which it was certificated. However, as noted during the investigation of the ATR-72 accident at Roselawn, during normal flight operations, pilots often cannot tell the difference between icing conditions that fall within the appendix C envelope and icing conditions outside the appendix C envelope.[24] (For example, a pilot cannot differentiate between 40 micron droplets and 100 micron droplets.) Because pilots often cannot determine whether icing conditions are consistent with "those considered in the certification process" (i.e., limited points within the appendix C certification envelope), or not (i.e., SLD icing conditions, or other potentially hazardous conditions that were not subjected to testing, analysis, or demonstration during icing certification work), it is virtually inevitable that the airplane will unknowingly be operated in icing conditions that fall outside the certification envelope, or in which the airplane had not demonstrated that it could operate safely.

Further, as has been recognized for 50 years or more, and demonstrated in accidents in the 1970s, 1980s, and early 1990s, and then again in the Comair flight 3272 accident, surface roughness/ice accretions that may be imperceptible or appear insignificant to pilots can adversely affect the operation of the airplane. However, because of the imperceptible or seemingly insignificant nature of those accretions, pilots who operate the airplane's deicing boots in accordance with manufacturer's guidance (that advises them to wait until a recommended thickness of ice accretes) may not activate the deicing boots under these circumstances. An article written by a Douglas Aircraft Company design engineer (published in January 1979) indicated that although most pilots are aware of the adverse aerodynamic effects of large amounts of ice, pilots appear less aware that seemingly insignificant amounts of thin, rough ice on an airfoil's leading edge can significantly degrade the airplane's flight characteristics. The deicing boot operating procedures now contained in most airplane manuals contribute to this lack of awareness by advising pilots to wait until a recommended thickness of ice accretes.

---

[24] The FAA has since required manufacturers of turbopropeller-driven airplanes to develop visual cues for SLD icing; however, the cues were based on very limited testing. Thus, the Safety Board is not convinced that such cues will exist for all icing conditions outside the appendix C icing envelope.

During the investigation of this accident, arguments were made that the pilots caused the accident because they accepted an airspeed 10 knots slower than Comair's FSM recommended for holding in icing conditions. However, the Safety Board notes that an EMB-120 loaded and configured similar to Comair flight 3272, and operated at 150 knots without any ice accretions, would have a 36-knot margin between its operating airspeed and the stall speed. This margin would likely appear to be an adequate safety margin to a pilot who did not recognize that the airplane was accumulating ice or did not believe that enough ice had accumulated to warrant activation of the deicing boots. The flight handling testing that occurred during the icing certification process did not identify that control problems that were observed in the accident airplane's performance at an airspeed of about 156 knots (only 4 knots below the 160-knot minimum speed for flight in icing conditions set by the FAA following the Comair accident) with only a small amount of ice accreted on the deicing boots. It is possible that if the FAA had required manufacturers to conduct tests with small amounts of rough-textured ice accreted on the protected surfaces (as might occur before boot activation and between boot cycles) during icing certification testing, the absence of an adequate safety margin above the stall speed would have been identified. Further, the FAA could have ensured pilot awareness of icing and adequate stall warning by requiring manufacturers to install ice detectors[25] and stall warning systems with reduced AOA thresholds for operations in icing conditions.

Based on its concerns that the current icing certification standards did not require testing for all realistic hazardous ice accretion scenarios, in its 1981 icing-related safety study, the Safety Board recommended that the FAA review the adequacy of the 1950s-era Part 25 appendix C icing envelope, update the procedures for aircraft icing certification, and oversee the manufacturers' evaluations of aircraft performance in various icing conditions. The circumstances of the Comair flight 3272 accident demonstrated again the continuing need for these FAA actions. The Safety Board considers the information that has been available regarding thin, rough ice accretions sufficient to have prompted the FAA to require additional testing within the appendix C envelope to demonstrate the effects of thin, rough ice as part of the icing certification process. Had the FAA required such additional testing, the resultant information regarding the stall margin and operational envelope of the EMB-120 might have been used to define minimum airspeeds for operating the airplane in icing conditions. Therefore, based on its review of the history of icing information, the icing-related incident and accident history, the EMB-120 initial icing certification data, the EMB-120 SLD icing controllability test results, and the circumstances of this accident, the Safety Board concludes that the icing certification process has been inadequate because it has not required manufacturers to demonstrate the airplane's flight handling and stall characteristics under a sufficiently realistic range of adverse ice accretion/flight handling conditions.

As a result of its investigation of the 1994 Roselawn accident, the Safety Board issued Safety Recommendations A-96-54 and A-96-56 (currently classified "Open—Acceptable Response"), which, respectively, stated that the FAA should do the following:

> Revise the icing criteria published in 14 CFR Parts 23 and 25, in light of both recent research into aircraft ice accretion under varying conditions of liquid water content, drop size distribution, and temperature, and recent developments in both the design

[25] Rosemount ice detectors were first used in military and transport-category airplanes in the early 1970s.

and use of aircraft. Also, expand the Appendix C icing certification envelope to include freezing drizzle/freezing rain and mixed water/ice crystal conditions, as necessary.

Revise the icing certification testing regulation to ensure that airplanes are properly tested for all conditions in which they are authorized to operate, or are otherwise shown to be capable of safe flight into such conditions. If safe operations cannot be demonstrated by the manufacturer, operational limitations should be imposed to prohibit flight in such conditions and flightcrews should be provided with the means to positively determine when they are in icing conditions that exceed the limits for aircraft certification.

Further, based on a perceived depletion of the FAA's technical expertise, the 1993 U.S. General Accounting Office report entitled "Aircraft Certification: New FAA Approach Needed to Meet Challenges of Advanced Technology" recommended that the FAA should hire more technical subject matter specialists in various areas, including that of environmental icing. After the Roselawn accident, the FAA developed a three-phase, multi-pronged plan to address icing-related concerns, including operational issues, forecasting/defining icing conditions, certification issues, validating simulation methods, identifying the aerodynamic effects of accretion, and identifying visual cues to various hazardous icing conditions and (about 2 years after the Roselawn accident) hired its current Environmental Icing National Resource Specialist (NRS). In January 1998, the FAA's Environmental Icing NRS updated the Safety Board on the FAA's progress with its plan, indicating that the first two phases have been completed and progress is being made in several aspects of Phase III (specifically in the areas of understanding the effects of various ice accretions, operational issues such as bridging, and development of ice detection/protection equipment).

The Safety Board notes that the FAA's three-phase plan could potentially satisfy the need for a comprehensive review of all aspects of structural icing in turbopropeller-driven transport airplanes. However, the regulatory/certification changes addressed during Phase III have encountered delays. FAA personnel reported to the Safety Board that their attempts to produce an advisory circular (AC) that would appropriately revise methods of compliance with Parts 23/25 and Part 25 appendix C were not successful;[26] therefore, they changed their approach to the problem and issued two of three proposed ACs addressing changes to methods of compliance and are going through the rulemaking process for the needed regulatory changes. According to FAA personnel, ACs addressing methods of compliance with Parts 23 and 25 were issued on August 19, 1998, and March 31, 1998, respectively, and the newly created AC 25.1419 is currently in draft form, with no estimated issue date available. FAA personnel estimated that the rulemaking process will probably not be completed until January 2000.

In response to the Safety Board's Safety Recommendations A-96-54 and A-96-56, the FAA assigned aviation rulemaking advisory committee (ARAC) working groups to accomplish, in part, the following: to establish criticality of ice accretions on airplane performance and handling

[26] According to the FAA's Environmental Icing NRS, FAA legal personnel determined that portions of the AC appeared to require regulatory changes and therefore could not be addressed solely by means of an AC.

qualities, to develop icing certification criteria for the safe operation of airplanes in icing conditions that are not covered by the current certification envelope, and to consider the development of a regulation requiring the installation of ice detectors or equivalent means to warn flightcrews of ice accumulations. The Safety Board appreciates the efforts of the FAA Environmental Icing NRS and the ARAC working groups, and the Safety Board concludes that the work conducted by the FAA Environmental Icing NRS and the ARAC icing-related working groups is of crucial importance to the future safety of icing operations. Consequently, the Safety Board believes that the FAA should expedite the research, development, and implementation of revisions to the icing certification testing regulations to ensure that airplanes are adequately tested for the conditions in which they are certificated to operate; the research should include identification (and incorporation into icing certification requirements) of realistic ice shapes and their effects and criticality. Further, the Board reiterates Safety Recommendation A-96-54 and A-96-56 to the FAA.

The Safety Board further notes that according to the FAA's EMB-120 Aircraft Certification Program Manager and Environmental Icing NRS, the new standards, criteria, and methods of compliance contained in Parts 23 and 25 and corresponding ACs that are currently being developed would be applied only to future icing certification projects and would not be retroactively applied to airplanes currently certificated for flight in icing conditions. The Safety Board is concerned that if the FAA does not retroactively apply the revised icing certification standards and methods of compliance to airplanes currently certificated for flight in icing conditions, flight handling/controllability anomalies that have not been accounted for may remain unaccounted for until after a fatal accident, as occurred in the ATR-72 accident at Roselawn and the EMB-120 accident at Monroe, Michigan. The Safety Board concludes that the potential consequences of operating an airplane in icing conditions without first having thoroughly demonstrated adequate handling/controllability characteristics in those conditions are sufficiently severe that they warrant as thorough a certification test program as possible, including application of revised standards to airplanes currently certificated for flight in icing conditions.

Therefore, the Safety Board believes that the FAA should, when the revised icing certification standards and criteria are complete, review the icing certification of all turbopropeller-driven airplanes that are currently certificated for operation in icing conditions and perform additional testing and take action as required to ensure that these airplanes fulfill the requirements of the revised icing certification standards. Further, pending the accomplishment of these actions, the Safety Board believes that the FAA should review turbopropeller-driven airplane manufacturers' AFMs and air carrier flightcrew operating manuals (where applicable) to ensure that these manuals provide operational procedures for flight in icing conditions, including the activation of leading edge deicing boots, the use of increased airspeeds, and disengagement of autopilot systems before entering icing conditions (that is, when other anti-icing systems have traditionally been activated).

FAA Policies for Airplane Flight Manuals and Air Carrier Operating Manual Revisions

Because FAA Order 8400.10, "Air Transportation Operations Inspector's Handbook," only requires operators to maintain a flight manual that complies with existing regulations and "safe operating procedures," Comair was not required to incorporate manufacturer-recommended procedures or revisions. In addition to the air carrier's decision not to incorporate the procedures contained in Embraer's EMB-120 AFM revision 43 into its own FSM, Comair also had not incorporated Embraer's long-standing procedures for the use of engine ignition and inlet deice boots in icing conditions. Because this investigation revealed several instances in which Comair elected not to incorporate potentially critical safety-of-flight AFM procedures into its operating manual and because the POI for Comair (although he had received a copy of AFM revision 43 from Embraer) was apparently not concerned by the operators' failure to incorporate such procedures, the Safety Board became concerned that the FAA's procedures for the management and oversight of air carriers' manuals may not be adequate.

Although it was somewhat controversial, revision 43 had been reviewed by FAA and CTA certification personnel and had been approved by these certification authorities as the proper way to operate the equipment. However, at the time of the accident, Comair and four of the other six U.S.-based EMB-120 operators had not incorporated revision 43 in their flightcrew operating manuals. This was possible, in part, because the FAA had not mandated incorporation of AFM revision 43 into operators' procedures. (Further, the FAA had not required Comair to incorporate AFM guidance advising pilots to increase approach airspeeds by 5 to 10 knots when operating in icing conditions.) In its October 1997 memo, the FAA stated that it would only issue an AD to mandate an AFM revision when it considered the change "significant enough to warrant retroactive application to all aircraft." No AD was issued when revision 43 to the EMB-120 AFM was approved; therefore, the FAA apparently did not consider the procedural changes contained in AFM revision 43 "significant enough" to require air carriers' compliance. Further, existing FAA policy does not require interaction or dialog between FAA flight standards and air carrier personnel regarding AFM procedures or revisions. Because Comair had not adopted the AFM revision 43 procedures, the pilots of flight 3272 were (unknowingly) operating in icing conditions without the most current, safest icing-related guidance. Had Comair incorporated AFM revision 43 into its EMB-120 operating procedures, the flightcrew might have activated the deicing boots before the loss of control of the airplane, possibly precluding the accident. Therefore, the Safety Board concludes that the current FAA policy allowing air carriers to elect not to adopt AFM operational procedures without clear written justification can result in air carriers using procedures that may not reflect the safest operating practices. The Safety Board believes that the FAA should require air carriers to adopt the operating procedures contained in the manufacturer's AFM and subsequent approved revisions or provide written justification that an equivalent safety level results from an alternative procedure.

Based on the history of revision 43 and the need for the FAA to more closely review and approve air carrier compliance with AFM procedures, the Safety Board assessed the capacity of the FAA flight standards organization to perform such an enhanced function. The Safety Board considers the FAA's current system inadequate because it allows for less than thorough review and communication regarding safety-of-flight data/information in a number of areas (i.e., certification, icing certification, continuing airworthiness/oversight). Before the Comair accident, the FAA POI who was responsible for oversight of Comair was not aware of the background information justifying revision 43 to the EMB-120 AFM and thus did not pursue corresponding procedural changes with Comair. According to a memo received by the Safety Board in October 1997 from FAA personnel (the Acting Director of Flight Standards Service and the Director of Aircraft Certification Service), at the time of the accident, there was no procedure to ensure that information (including AFM changes) not mandated by an AD was shared between ACO and/or AEG personnel and other Flight Standards personnel (specifically, the POIs). The memo stated that although informal communications (described by FAA personnel as "discretionary") can occur in some cases between ACO and/or AEG personnel and POIs, there was no formal procedure to ensure that the necessary communication and coordination take place. (The memo further stated that the airplane operators "typically supply that revision to the POI.")

According to the authors of the memo, when the FAA receives an AFM revision from a manufacturer, the ACO personnel would not engage in discussions with Flight Standards personnel unless they believed that the AFM revision was particularly noteworthy, in which case they would discuss it with flight standards AEG personnel. Further, there was no explicit line of communication between the AEG and POIs. Thus, under the current system, the POI (or other pertinent flight standards personnel) might never know about the revision (if ACO personnel deemed it unnoteworthy) unless they receive a copy from the manufacturer (as was the case with Embraer's AFM revision 43) or unless an operator requests approval for an associated change to its flightcrew operating manual.

The Safety Board has observed similar communication/coordination problems between FAA offices during other investigations—specifically, during the investigation of the 1987 CASA C-212-CC accident at Romulus, Michigan, and the 1994 ATR-72 accident at Roselawn. As a result of the ATR-72 accident, the Safety Board recommended (in Safety Recommendation A-96-62) that the FAA develop an organizational structure and communications system to ensure that accident/incident information is disseminated to ensure effective continuing airworthiness oversight, with specific emphasis on the AEG. In April 1997, the FAA agreed that it would review its then-current organizational structure and processes to determine the adequacy of the communications and monitoring of the continuing airworthiness of aircraft, and the Safety Board classified the recommendation "Open—Acceptable Response." On February 25, 1998, the FAA responded that it had initiated positive improvements. Based on this action and the Board's continuing dialogue with the FAA on this issue, Safety Recommendation A-96-62 remains classified "Open—Acceptable Response."

During a June 11, 1998, meeting, FAA management personnel advised Safety Board staff that the FAA had completed the review of its internal communications procedures and had identified areas in which improvements were warranted. The Director of Aircraft Certification Services stated that the FAA is "committed to making changes, [and is] putting a team together" to establish new procedures to ensure that information is shared with all pertinent personnel in all branches of the FAA. He reported that under the new system, the ACO Project Manager and Flight Test Manager will discuss all flight manual revisions with flight standards AEG personnel, who will in turn discuss the revisions with the POIs whose operators are affected; the discussions will not hinge on a subjective determination of significance, and a dispute resolution process will be established. The Safety Board considers these improved communication procedures to be essential under both the existing FAA policy in which air carrier adoption of AFM procedures is optional, and the Safety Board's proposed policy that would in most cases mandate adoption of these procedures. Under the proposed policy, flight standards and ACO personnel would need to coordinate the evaluation of AFM revisions and the equivalence of alternatives proposed by the air carriers.

Thus, the Safety Board concludes that at the time of the Comair flight 3272 accident, pertinent flight standards personnel (specifically, the POI assigned to Comair) lacked information critical to the continued safe operation of the EMB-120 fleet and would have been unable to evaluate the need to incorporate AFM revision 43 or any alternatives proposed by air carriers. Therefore, the Safety Board believes that the FAA should ensure that flight standards personnel at all levels (from AEGs to certificate management offices) are informed about all manufacturer OBs and AFM revisions, including the background and justification for the revision.

Westair EMB-120 FDR Sensor Information

The Safety Board has observed anomalous FDR-recorded values for flight control parameters on seven of eight Embraer EMB-120 FDRs it has reviewed, including the FDRs from the Comair and the Westair airplanes. The Westair incident occurred after the FAA established new FDR inspection/potentiometer calibration requirements for operators of EMB-120 airplanes, and Westair's maintenance records indicated that an FDR system check was conducted on the incident airplane on December 27, 1997, with no system discrepancies noted. The test procedure was conducted with the airplane stationary and the engines not running; there was no requirement for an FDR readout during the test procedure.

Although there were no sensor discrepancies noted during the Westair FDR system check, the Safety Board's postincident review of the incident airplane's FDR data revealed discrepancies in the control wheel and rudder pedal position parameters. The Safety Board's evaluation of the potentiometer calibration test criteria and the symptoms displayed by the problem sensors indicated that the sensor anomalies may not have been detectable during static tests on the ground. The test procedure did not provide an evaluation of sensor performance under normal operating conditions and, therefore, may be of limited use in detecting noisy signals or invalid signals that are confined to only a portion of the sensor's normal operating range. The Safety Board considers it likely that if an FDR readout had been conducted and pertinent parameters reviewed in conjunction with the FDR system check, the control wheel position and rudder sensor anomalies would have been observed, and efforts would have been taken to correct them.

Reliable FDR information is critical to understanding accident/incident scenarios and invaluable in identifying complex safety issues and solutions; when FDR information is not recorded (or is recorded incorrectly) for any given parameter, it becomes more likely that potentially significant safety issues will not be identified. Further (as noted in the Safety Board's report regarding the August 1997 accident involving a Fine Airlines Douglas DC-8-61 at Miami, Florida),[27] reliable FDR data, read out at regular inspection intervals, can be useful for purposes other than accident/incident investigation. Analysis of such FDR data could be used by operators to monitor trends and efficiency in their flight operations through a flight operations quality

[27] See National Transportation Safety Board. 1998. *Fine Airlines Flight 101, Douglas DC-8-61, N27UA, Miami, Florida, August 7, 1997.* Aircraft Accident Report NTSB/AAR-98/02. Washington, DC.

assurance program and could be used on an industry-wide basis to streamline flight operations, refine ATC procedures and airport configurations, and improve aircraft designs.

The Safety Board concludes that the FAA's current EMB-120 FDR system inspection procedure is inadequate because it allows existing flight control sensor anomalies to go undetected, and thus uncorrected. Therefore, the Safety Board believes that the FAA should revise its current EMB-120 FDR system inspection procedure to include an FDR readout and evaluation of parameter values from normal operations to ensure a more accurate assessment of the operating status of the flight control position sensors on board the airplane.

The Lack of Additional Icing-Related Pilot Reports

The Safety Board's investigation of the meteorological aspects of this accident revealed that about 16 icing-related pilot reports (PIREPs) were issued by pilots operating in the northwestern Ohio/southern Michigan area between 1300 and 1700 on the day of the accident. However, when the Safety Board distributed a weather conditions survey to additional flightcrews that were operating near Detroit about the time of the accident, 9 of the 11 pilots who responded to the survey reported that they encountered icing conditions. Of the nine pilots who indicated that they encountered icing conditions, only one pilot had submitted a pilot report for the conditions they observed on the day of the accident. (In response to a survey question that asked if they submitted a PIREP, two pilots stated that they did not submit a PIREP because the conditions encountered were consistent with the forecast icing conditions; one pilot reported that he did not submit a PIREP because of accident-related congestion on the ATC frequency; and the pilots of another airplane reported that they were too busy during the approach, landing, and taxi to submit a PIREP. The survey responses from the other four responding pilots did not state why they did not submit PIREPs.)

Although the Safety Board does not believe that the absence of these additional PIREPs affected the accident flightcrew's actions (because they were provided with adequate preflight, en route, and arrival weather information to conduct the flight safely; they should have been aware that they would be operating in potential icing conditions), it is possible that the PIREP information would have greatly benefited other pilots. Because PIREPs are an important and valuable source of weather information for pilots, the Safety Board is concerned that pilots had observed icing in the Detroit area the day of the accident but did not share that information with other pilots. Thus, the Safety Board concludes that the failure of pilots who encounter in-flight icing to report the information to the appropriate facility denies other pilots operating in the area the access to valuable and timely information that could prevent an accident. Therefore, the Safety Board believes that the FAA should reemphasize to pilots, on a periodic basis, their responsibility to report meteorological conditions that may adversely affect the safety of other flights, such as in-flight icing and turbulence, to the appropriate facility as soon as practicable.

Also, because a Detroit air traffic controller did not disseminate icing-related information that he had received from another flight operating in the area about 20 minutes before the accident, the Safety Board examined the dissemination of icing-related information through the ATC system. The Board notes that the Standard Operating Procedures handbook for DTW Air Traffic Control Tower and Terminal Radar Approach Control did not require that icing reports be included on the automatic terminal information service (ATIS) recording that is monitored by all pilots. Although FAA Order 7110.65, "Air Traffic Control," contains guidance that PIREPs of any type should be included in the ATIS broadcast "as appropriate" and "pertinent to operations in the terminal area," this guidance is too broad and subjective to adequately ensure the transmission of icing-related information in an airport terminal environment. Reports of icing conditions should be of interest to all pilots operating within that environment, especially considering the normally reduced airspeeds and decreased stall margins for airplanes operating in the approach and departure phases of flight. Therefore, the Safety Board concludes that the FAA ATC system has not established adequate procedures for the dissemination of icing-related pilot reports received in the airport terminal environment; these reports should be incorporated into ATIS broadcasts so that all arriving and departing pilots can become aware of icing conditions in the area. Consequently, the Safety Board believes that the FAA should amend FAA Order 7110.65, "Air Traffic Control," to require that ATIS broadcasts include information regarding the existence of pilot reports of icing conditions in that airport terminal's environment (and adjacent airport terminal environments as meteorologically pertinent and operationally feasible) as soon as practicable after receipt of the pilot report.

Therefore, the National Transportation Safety Board makes the following recommendations to the Federal Aviation Administration:

> Amend the definition of trace ice contained in Federal Aviation Administration (FAA) Order 7110.10L, "Flight Services," (and in other FAA documents as applicable) so that it does not indicate that trace icing is not hazardous. (A-98-88)
>
> Require principal operations inspectors (POIs) to discuss the information contained in airplane flight manual revisions and/or manufacturers' operational bulletins with affected air carrier operators and, if the POI determines that the information contained in those publications is important information for flight operations, to encourage the affected air carrier operators to share that information with the pilots who are operating those airplanes. (A-98-89)
>
> With the National Aeronautics and Space Administration and other interested aviation organizations, organize and implement an industry-wide training effort to educate manufacturers, operators, and pilots of air carrier and general aviation turbopropeller-driven airplanes regarding the hazards of thin, possibly imperceptible, rough ice accumulations, the importance of activating the leading edge deicing boots as soon as the airplane enters icing conditions (for those airplanes in which ice bridging is not a concern), and the importance of maintaining minimum airspeeds in icing conditions. (A-98-90)
>
> Require manufacturers and operators of modern turbopropeller-driven airplanes in which ice bridging is not a concern to review and revise the guidance contained in their manuals and training programs to include updated icing information and to emphasize that leading edge deicing boots should be activated as soon as the airplane enters icing conditions. (A-98-91)

With the National Aeronautics and Space Administration and other interested aviation organizations, conduct additional research to identify realistic ice accumulations, to include intercycle and residual ice accumulations and ice accumulations on unprotected surfaces aft of the deicing boots, and to determine the effects and criticality of such ice accumulations; further, the information developed through such research should be incorporated into aircraft certification requirements and pilot training programs at all levels. (A-98-92)

Actively pursue research with airframe manufacturers and other industry personnel to develop effective ice detection/protection systems that will keep critical airplane surfaces free of ice; then require their installation on newly manufactured and in-service airplanes certificated for flight in icing conditions. (A-98-93)

Require manufacturers of all turbine-engine driven airplanes (including the EMB-120) to provide minimum maneuvering airspeed information for all airplane configurations, phases, and conditions of flight (icing and nonicing conditions); minimum airspeeds also should take into consideration the effects of various types, amounts, and locations of ice accumulation, including thin amounts of very rough ice, ice accumulated in supercooled large droplet icing conditions, and tailplane icing. (A-98-94)

Require the operators of all turbine-engine driven airplanes (including the EMB-120) to incorporate the manufacturer's minimum maneuvering airspeeds for various airplane configurations and phases and conditions of flight in their operating manuals and pilot training programs in a clear and concise manner, with emphasis on maintaining minimum safe airspeeds while operating in icing conditions. (A-98-95)

Require the manufacturers and operators of all airplanes that are certificated to operate in icing conditions to install stall warning/protection systems that provide a cockpit warning (aural warning and/or stick shaker) before the onset of stall when the airplane is operating in icing conditions. (A-98-96)

Require all operators of turbopropeller-driven air carrier airplanes to require pilots to disengage the autopilot and fly the airplane manually when they activate the anti-ice systems. (A-98-97)

Require all manufacturers of transport-category airplanes to incorporate logic into all new and existing transport-category airplanes that have autopilots installed to provide a cockpit aural warning to alert pilots when the airplane's bank and/or pitch exceeds the autopilot's maximum bank and/or pitch command limits. (A-98-98)

Expedite the research, development, and implementation of revisions to the icing certification testing regulations to ensure that airplanes are adequately tested for the conditions in which they are certificated to operate; the research should include identification (and incorporation into icing certification requirements) of realistic ice shapes and their effects and criticality. (A-98-99)

When the revised icing certification standards and criteria are complete, review the icing certification of all turbopropeller-driven airplanes that are currently certificated for operation in icing conditions and perform additional testing and take action as required to ensure that these airplanes fulfill the requirements of the revised icing certification standards. (A-98-100)

Review turbopropeller-driven airplane manufacturers' airplane flight manuals and air carrier flightcrew operating manuals (where applicable) to ensure that these manuals provide operational procedures for flight in icing conditions, including the activation of leading edge deicing boots, the use of increased airspeeds, and disengagement of autopilot systems before entering icing conditions (that is, when other anti-icing systems have traditionally been activated). (A-98-101)

Require air carriers to adopt the operating procedures contained in the manufacturer's airplane flight manual and subsequent approved revisions or provide written justification that an equivalent safety level results from an alternative procedure. (A-98-102)

Ensure that flight standards personnel at all levels (from aircraft evaluation groups to certificate management offices) are informed about all manufacturer operational bulletins and airplane flight manual revisions, including the background and justification for the revision. (A-98-103)

Revise its current EMB-120 flight data recorder (FDR) system inspection procedure to include a FDR readout and evaluation of parameter values from normal operations to ensure a more accurate assessment of the operating status of the flight control position sensors on board the airplane. (A-98-104)

Reemphasize to pilots, on a periodic basis, their responsibility to report meteorological conditions that may adversely affect the safety of other flights, such as in-flight icing and turbulence, to the appropriate facility as soon as practicable. (A-98-105)

Amend Federal Aviation Administration Order 7110.65, "Air Traffic Control," to require that automatic terminal information service broadcasts include information regarding the existence of pilot reports of icing conditions in that airport terminal's environment (and adjacent airport terminal environments as meteorologically pertinent and operationally feasible) as soon as practicable after receipt of the pilot report. (A-98-106)

In addition, the Safety Board reiterates the following safety recommendations to the Federal Aviation Administration:

Revise the icing criteria published in 14 Code of Federal Regulations Parts 23 and 25, in light of both recent research into aircraft ice accretion under varying conditions of liquid water content, drop size distribution, and temperature, and recent development in both the design and use of aircraft. Also, expand the Part 25 appendix C icing certification envelope to include freezing drizzle/freezing rain and mixed water/ice crystal conditions, as necessary. (A-96-54)

Revise the icing certification testing regulation to ensure that airplanes are properly tested for all conditions in which they are authorized to operate, or are otherwise shown to be capable of safe flight into such conditions. If safe operations cannot be demonstrated by the manufacturer, operational limitations should be imposed to prohibit flight in such conditions and flightcrews should be provided with the means to positively determine when they are in icing conditions that exceed the limits for aircraft certification. (A-96-56)

Chairman HALL, Vice Chairman FRANCIS,** and Members HAMMERSCHMIDT, GOGLIA, and BLACK concurred in these recommendations.

By: Jim Hall
Chairman

**Vice Chairman Francis did not participate in the vote to reiterate Safety Recommendations A-96-54 and A-96-56.

National Transportation Safety Board

Washington, D.C. 20594

Safety Recommendation

Date: November 30, 1998

In reply refer to: A-98-107 to -108

Honorable Daniel S. Goldin
Administrator
National Aeronautics and Space Administration
Washington, D.C. 20546

About 1554 eastern standard time,[1] on January 9, 1997, an Empresa Brasileira de Aeronautica, S/A (Embraer) EMB-120RT, N265CA, operated by COMAIR Airlines, Inc.,[2] as flight 3272, crashed during a rapid descent after an uncommanded roll excursion near Monroe, Michigan. Comair flight 3272 was being operated under the provisions of Title 14 Code of Federal Regulations (CFR) Part 135 as a scheduled, domestic passenger flight from the Cincinnati/Northern Kentucky International Airport (CVG), Covington, Kentucky, to Detroit Metropolitan/Wayne County Airport (DTW), Detroit, Michigan. The flight departed CVG about 1508, with 2 flightcrew members, 1 flight attendant, and 26 passengers on board. There were no survivors. The airplane was destroyed by ground impact forces and a postaccident fire. Instrument meteorological conditions prevailed at the time of the accident, and flight 3272 was operating on an instrument flight rules flight plan.

The National Transportation Safety Board determined that the probable cause of this accident was the Federal Aviation Administration's (FAA) failure to establish adequate aircraft certification standards for flight in icing conditions, the FAA's failure to ensure that a Centro Tecnico Aeroespacial/FAA-approved procedure for the accident airplane's deice system operation was implemented by U.S.-based air carriers, and the FAA's failure to require the establishment of adequate minimum airspeeds for icing conditions, which led to the loss of control when the airplane accumulated a thin, rough accretion of ice on its lifting surfaces.[3]

[1] Unless otherwise indicated, all times are eastern standard time, based on a 24-hour clock.

[2] Within this safety recommendation letter, COMAIR Airlines, Inc., will be identified as Comair.

[3] National Transportation Safety Board. 1998. *In-Flight Icing Encounter and Uncontrolled Collision With Terrain, Comair Flight 3272, Embraer EMB-120RT, N265CA, Monroe, Michigan, January 9, 1997.* Aircraft Accident Report NTSB/AAR-98/04. Washington, DC.

Summary of Accident Sequence

According to cockpit voice recorder (CVR) and air traffic control (ATC) information, during the 20 minutes preceding the accident, the pilots received a series of clearances from ATC that included descent, airspeed, and heading instructions. Flight data recorder (FDR) and radar data indicated that the airplane's descent from the en route cruise altitude of flight level 210 to 4,000 feet mean sea level (msl) was stable and controlled and was accomplished at airspeeds and headings consistent with those assigned by ATC. Meteorological information and pilot reports indicated that the airplane was probably intermittently in clouds as it descended between about 11,000 feet msl and 8,200 feet msl; below 8,200 feet msl, the airplane was probably operating predominantly in the clouds.

The pilots were operating with the autopilot engaged during the descent. They had completed the descent checklist (including the activation of the propeller deicing and windshield heat at the ice protection checklist prompt) and the first four of the six items on the approach checklist[4] before the airplane reached 4,000 feet msl during its descent. At 1553:59, when the autopilot was leveling the airplane at 4,000 feet msl on a heading of 180°, the airplane was in the clean configuration (no flaps or gear extended) at an airspeed of about 166 knots (the pilots were beginning to reduce the airspeed to the ATC-assigned airspeed of 150 knots). At that time, ATC instructed the pilots of flight 3272 to turn left to a heading of 090°. Shortly after the pilots initiated the left turn (by selecting the assigned heading for the autopilot), the airplane reached its selected altitude and (at 1554:08) the autopilot automatically transitioned to the altitude hold mode. As the autopilot attempted to maintain the selected altitude, the airplane's angle-of-attack (AOA) began to increase and the airspeed continued to decrease; at 1554:10, the autopilot began to trim the elevator (pitch trim) to an increasingly nose-up position.

The accident airplane's FDR data indicated that at 1554:10 the airplane's left bank steepened beyond 20° (moving toward the autopilot's command limit in the heading mode of 25°, +/- 2.5°). At that point (according to the autopilot design and FDR information), the roll rate exceeded that required by the autopilot's design logic to achieve the commanded roll angle, and the autopilot's input to the aileron servos moved the ailerons (and thus the airplane's control wheel) in the right-wing-down direction to counter the increasing left roll rate. FDR data indicated that, during the next 3 seconds, the left and right AOA vanes began to diverge, indicating a left sideslip/yaw condition, and the lateral acceleration values began to increase to the left while the autopilot increased the control wheel input to the right in an attempt to control the roll. Thus, by 1554:10, as the airspeed decreased through 155 knots, the airplane experienced the beginning of a significant asymmetry in the lift distribution between the right and left wings and an uncommanded yaw and roll to the left.[5] The roll and control wheel position parameters continued

[4] According to several Comair EMB-120 pilots, the remaining approach checklist items—flight attendants, notified and flaps, 15/15/checked—would normally be accomplished later during the approach, as the airplane neared the destination airport.

[5] Evaluation of the FDR information revealed that a slight asymmetry of lift because of ice existed earlier in the flight; however, it became aerodynamically significant about 1554:10.

to trend in opposite directions, and the left and right AOA vanes continued to split for the next 14 seconds, until the autopilot disconnected at 1554:24.125.

Just after 1554:15, as the airplane's airspeed began to decrease below 150 knots, the pilots began to increase the engine power;[6] however, the airplane's airspeed continued to decrease. When the captain drew the first officer's attention to the low airspeed indication at 1554:20.8, the airplane's airspeed had decreased to 147 knots. During the next 2 seconds, the pilots more aggressively increased the engine power, and a significant torque split occurred; the torque values peaked at 108 percent on the left engine and 138 percent on the right engine. The Safety Board considered several possible reasons for the significant torque split, including uneven throttle movement by the pilots, ice ingestion by the left engine, a misrigged engine, or an improper engine trim adjustment on the newly installed right engine; however, it was not possible to positively determine the cause of the torque split. Postaccident simulations indicated that this torque split had a significant yaw-producing effect at a critical time in the upset event, exacerbating the airplane's excessive left roll tendency. The airplane's airspeed decreased further to 146 knots, the left roll angle increased beyond the autopilot's 45° limit, and (at 1554:24.1) the autopilot disconnect warning began to sound. One second later, the stick shaker activated. The sudden disengagement of the autopilot (at 1554:24.125) greatly accelerated the left rolling moment that had been developing, suddenly putting the airplane in an unusual attitude. Although the pilots were likely surprised by the upset event, interpretation of the FDR data indicated that the pilots responded with control wheel inputs to counter the left roll within 1 second of the autopilot disengagement and continued to apply control inputs in an apparent attempt to regain control of the airplane until the FDR recording ceased.

Meteorological Factors

Although Comair flight 3272 was operating in winter weather conditions throughout its flight from the Cincinnati area to Detroit, CVR and weather information indicated that the airplane was operating above the cloud tops at its cruise altitude of 21,000 feet msl. Further, the temperatures at the altitudes flown during the en route phase of the flight were too cold to be conducive to airframe ice accretion, and examination of the FDR data did not reflect degraded airplane performance until later in the airplane's descent. Therefore, the Safety Board concludes that the airplane was aerodynamically clean, with no effective ice accreted, when it began its descent to the Detroit area.

A study conducted by the National Center for Atmospheric Research (NCAR) indicated that there was strong evidence for the existence of icing conditions in the clouds along the accident airplane's descent path below 11,000 feet msl. In addition, weather radar data showed generally light precipitation intensities in the area west of Detroit, with weather echoes of increasing intensity below 11,000 feet msl along the airplane's descent path. The weather radar

[6] An engine torque split manifested itself during this application of power—at 1554:17, the FDR recorded torque values of 33.3 percent and 39.3 percent on the left and right engines, respectively. The engine torque split ranged from 6 to 10 percent between 1554:17 and 1554:22, when torque values (and the range of the torque split) began to increase abruptly. Simulator test flights that replicated the accident scenario demonstrated that the initial 6 to 10 percent torque split did not have a large aerodynamic effect on the airplane's left roll; however, the larger torque split that occurred later in the accident sequence had a significant aerodynamic effect.

data indicated that the highest precipitation intensities likely existed between 4,100 feet msl and 3,900 feet msl.

The NCAR research meteorologists reported that the average liquid water content (LWC) in the clouds near the accident site likely varied from 0.025 to 0.4 grams per cubic meter when averaged over the cloud depth. However, according to an NCAR research meteorologist, droplet size and LWC are rarely evenly distributed through the depth of a cloud; he stated that, in a typical cloud distribution, the larger droplet sizes with corresponding lower LWC would likely exist near the cloud bases, whereas smaller droplet sizes with higher LWC would typically exist near the cloud tops. He stated that the accident airplane might have encountered higher LWC values (0.5-0.8 grams per cubic meter) with smaller droplets (non-supercooled large droplets (SLD), 10-30 microns) near the cloud tops and lower LWC values (0.025 to 0.4 grams per cubic meter) with larger droplets (larger than 30 microns) near the cloud bases (consistent with the previously discussed weather radar data). Further, the NCAR research meteorologist stated, "if any SLD existed…it would have been more likely to be lower in the cloud…be mixed with smaller drops…the larger drops in the spectrum of those that may have existed there would have been in the 200-400 micron…range."

In addition, the accident airplane's descent path passed through an area of relatively low radar reflectivity during the 4 to 5 minutes before the accident. According to the NCAR report, the area of reduced reflectivity indicated that "the snow-making process was less efficient there, thus allowing a greater opportunity for liquid cloud to exist." Postaccident statements obtained from the other pilots who were operating along the accident airplane's flightpath (and passed through the area of low reflectivity) near the time of the accident indicated that they encountered widely variable conditions. For example, the pilots of Cactus 50 reported moderate rime icing with the possibility of freezing drizzle, the pilots of Northwest Airlines (NW) flight 272 encountered moderate-to-severe rime icing as soon as they leveled off at 4,000 feet msl, and the pilots of NW flight 483 reported no icing.

Comparison of data from the airplanes indicates that the differences in airframe ice accretion reported by the pilots can be attributed to slight differences in timing, altitude, location (ground track), airspeed, and icing exposure time (and time within the area of reduced reflectivity) of the airplanes. Based on weather radar information and pilot statements, the Safety Board concludes that the weather conditions near the accident site were highly variable and were conducive to the formation of rime or mixed ice at various altitudes and in various amounts, rates, and types of accumulation; if SLD icing conditions were present, the droplet sizes probably did not exceed 400 microns and most likely existed near 4,000 feet msl.

Aerodynamic Effect of the Ice Accretion

To help assess the type, amount, and effect of the ice that might have been accumulated by Comair flight 3272 during its descent, the Safety Board reviewed the available icing and wind tunnel research data, conducted additional airplane performance studies/simulations, and requested the National Aeronautics and Space Administration's (NASA's) assistance in conducting icing research tunnel (IRT) tests and computational studies. In addition, the Safety

Board reviewed wind tunnel test data obtained during research conducted by the FAA at the University of Illinois at Urbana/Champaign (UIUC).

The Safety Board's study of the accident airplane's aerodynamic performance indicated that it began to degrade from ice accumulation[7] about 4½ to 5 minutes before the autopilot disengaged, as the airplane descended through 7,000 feet msl; the amount of degradation increased gradually as the airplane descended to 4,000 feet msl. Based on this gradual performance degradation, weather radar data that showed light precipitation intensities, pilot reports of moderate or less ice accretions,[8] and the Safety Board and NCAR weather studies, it appeared likely that Comair flight 3272 encountered icing conditions that fell within the 14 CFR Part 25 appendix C envelope[9] and/or the lower portion of the SLD icing range during its descent to 4,000 feet msl. Thus, the postaccident icing tunnel tests were performed using LWCs between 0.52 and 0.85 grams per cubic meter and water droplet sizes between 20 microns and 270 microns. Total air temperatures (TAT) used in the icing tunnel tests ranged between 26° F and 31° F (-3° C and -0.5° C),[10] consistent with the static air temperature (SAT) values recorded by the FDR during the airplane's descent from 7,000 to 4,000 feet msl. The exposure time used in the icing tunnel tests was 5 minutes; additional runs were conducted under some test conditions to determine the effect that deicing boot activation had on cleaning the leading edge and on subsequent ice accretions.

The icing tunnel tests did not result in thick ice accumulation under any test condition (including SLD droplets); rather, the tests consistently resulted in a thin (0.25 inch accumulation or less), rough "sandpaper-type" ice coverage over a large portion of the airfoil's leading edge deicing boot surface area (and aft of the deicing boot on the lower wing surface in some test conditions). In addition, in many IRT test conditions, small (½ inch) ice ridges accreted along the leading edge deicing boot seams. According to NASA and Safety Board IRT test observers, the thin, rough ice coverages (and ice ridges, where applicable) that accreted on the EMB-120 wing were somewhat translucent and were often difficult to perceive from the observation window. The IRT observers further noted that IRT lighting conditions and cloud (spray) type greatly affected the conspicuity of the ice accumulation, making it difficult to perceive the ice accumulation during the icing exposure periods. Scientists at NASA's Lewis Research Center described the IRT ice accretions as mostly "glaze" ice, like mixed or clear ice in nature, although it looked slightly like rime ice when the IRT was brightly lighted for photographic documentation of the ice accretions because of its roughness. The Safety Board notes that it is possible that such an accumulation would be difficult for pilots to perceive visually during flight, particularly in low

[7] Although the Safety Board considered other possible sources for the aerodynamic degradation (such as a mechanical malfunction), the physical evidence did not support a system or structural failure, and the FDR data indicated a gradual, steadily increasing performance degradation that was consistent with degradation observed by the Safety Board in data from events in which icing was a known factor.

[8] All pilot reports indicated moderate or less ice accretions, except the pilots of NW flight 272, who reported that they encountered a trace of rime ice during the descent, then encountered moderate-to-severe icing at 4,000 feet msl about 2 minutes after the accident.

[9] The Part 25 appendix C icing envelope specifies the water drop mean effective diameter, the LWC, and the temperatures at which the airplane must be able to safely operate; aircraft compliance must be demonstrated through analysis, experimentation, and flight testing.

[10] These TATs are equivalent to SATs of 21° F (-6° C) to 25.5° F (-3° C).

light conditions. This type of accumulation would be consistent with the accident airplane's CVR, which did not record any crew discussion of perceived ice accumulation and/or the need to activate deicing boots during the last 5 minutes of the accident flight.

The location of rough ice coverage observed during the icing tunnel tests varied, depending on AOA; at lower AOAs, the ice accretions extended farther aft on the upper wing surface (to the aft edge of the deicing boot on the upper wing surface, about 7 percent of the wing chord at the aileron midspan), whereas at higher AOAs, the ice accretions extended farther aft on the lower wing surface. In some IRT test conditions, sparse feather-type ice accretion extended aft of the deicing boot coverage on the lower wing surface (which extends to about 10½ percent of the airfoil chord at the aileron midspan) as far as 30 to 35 percent of the airfoil's chord.[11]

The density of the rough ice coverage also varied, depending on the exposure time; a sparse layer of rough ice usually accreted on the entire impingement area during the first 30 seconds to 1 minute of exposure, and the layer became thicker and more dense as exposure time increased. The NASA-Lewis and FAA/UIUC tests indicated that thin, rough ice accretions located on the leading edge and lower surface of the airfoil primarily resulted in increases in drag, while thin, rough ice accretions located on the leading edge and upper wing surface had an adverse effect on both lift and drag; this is consistent with information that has been obtained during National Advisory Committee for Aeronautics/NASA icing research conducted since the late 1930s. Data from research conducted in the 1940s and 1950s indicate that an airfoil's performance can be significantly affected by even a relatively small amount of ice accumulated on the leading edge area, if that accumulation has a rough, sandpaper-type surface.

Consistent with these data, NASA's drag calculations indicated that the thin, rough layer of sandpaper-type ice accumulation resulted in significant drag and lift degradation on the EMB-120 wing section. Further, the thin rough ice accumulation resulted in a decrease in stall AOA similar to that observed in wind tunnel tests with 3-inch ram's horn ice shapes on protected surfaces and frequently demonstrated a more drastic drop off/break at the stall AOA. FAA/UIUC conducted wind tunnel tests using generic shapes to represent the sandpaper-type roughness with ridges placed on the upper wing surface at 6 percent of the wing chord (farther aft than the ice ridges observed during NASA's IRT tests); these tests further demonstrated that the ridge type of ice accretion resulted in more adverse aerodynamic effect than the 3-inch ram's horn ice shapes.

---

[11] According to NASA-Lewis scientists, some of the frost accretion observed aft of the deicing boot on the lower wing surface during the icing tunnel tests might have been an artifact of the icing research tunnel (resulting from the higher turbulence, humidity, and heat transfer characteristics of the tunnel). However, the B.F. Goodrich impingement study (which predicts ice accretion impingement limits on an airfoil) and NASA's LEWICE computer program (which predicts the extent of ice accretion on the leading edges of airplane wings and impingement limits and ice thickness for specified conditions but cannot predict surface roughness features) also predicted a sparse, rough ice accretion aft of the deicing boot on the lower wing surface for some of the tested conditions. However, no ice accretion aft of the deicing boot was noticed during the natural icing certification tests. Although it is possible that some of the drag observed in the accident airplane's performance was the result of a sparse, rough ice accumulation aft of the deicing boot on the lower wing surface, it was not possible to positively determine whether the accident airplane's ice accretion extended beyond the deicing boot coverage.

As previously noted, NASA's IRT tests indicated that when an EMB-120 wing is exposed to conditions similar to those encountered by Comair flight 3272 before the accident, the airfoil tended to accrete a small ice ridge (or ridges) along the deicing boot tube segment stitchlines. During tests conducted at a TAT of 26° F, a small, but prominent (½ inch) ridge of ice frequently appeared on the forward portion (0.5 to 1 percent mean aerodynamic chord) of the leading edge deicing boot's upper surface.

The IRT test results were used in NASA's computational studies, which indicated that these pronounced ice ridges tended to act as stall strips, creating more disrupted airflow over the airfoil's upper surface, further decreasing the lift produced by the airfoil, and resulting in a lower stall AOA than the rough ice accretions alone. NASA's computational study data indicated that a thin, rough ice accretion with a small, prominent ice ridge can result in a lower stall AOA and a more dramatic drop off/break than the 3-inch ram's horn ice shape commonly used during initial icing certification testing.

The accident airplane's performance displayed evidence of adverse effects on both lift and drag during the airplane's descent to 4,000 feet msl. The degradation exhibited by the accident airplane was consistent with a combination of thin, rough ice accumulation on the impingement area (including both upper and lower wing leading edge surfaces), with possible ice ridge accumulation. Thus, based on its evaluation of the weather, radar, drag information, CVR, existing icing research data, and postaccident icing and wind tunnel test information, the Safety Board concludes that it is likely that Comair flight 3272 gradually accumulated a thin, rough glaze/mixed ice coverage on the leading edge deicing boot surfaces, possibly with ice ridge formation on the leading edge upper surface, as the airplane descended from 7,000 feet msl to 4,000 feet msl in icing conditions; further, this type of ice accretion might have been imperceptible to the pilots.

The Safety Board notes that in some icing exposure scenarios, pilots could become aware of the performance degradation without observing a significant accumulation of ice on the airplane by observing other cues, such as a decrease in airspeed, excessive pitch trim usage, a higher-than-normal amount of engine power needed to maintain a stabilized condition, and/or anomalous rates of climb or descent. However, the Safety Board concludes that because the pilots of Comair flight 3272 were operating the airplane with the autopilot engaged during a series of descents, right and left turns, power adjustments, and airspeed reductions, they might not have perceived the airplane's gradually deteriorating performance.

Further, although it is possible (based on the icing reported by the pilots of NW flight 272 and the NCAR scientist's estimation of the likely droplet size distribution in the clouds) that the accident flight encountered SLD icing[12] as it reached 4,000 feet msl, the airplane was only at that altitude for about 25 seconds before the upset occurred; during most of that 25 seconds, the FDR data showed that the autopilot was countering the increasing left roll tendency and a sideslip

[12] Results from the SLD icing tanker tests suggest that the visual cues for SLD ice accumulations (unusually extensive ice accreted on the airframe in areas not normally observed to collect ice, accumulation of ice on the upper surface of the wing aft of the protected area, and on the propeller spinner farther aft than normally observed) would have been very apparent to the pilots and might have resulted in a comment.

condition was developing. However, even if the accident flight had accumulated ice at the rapid rate reported by the pilots of NW flight 272 (about ½ inch per minute), the accident flight could not have accumulated a large amount of ice during the brief period of time it spent at 4,000 feet before the autopilot disengaged and the loss of control occurred. Further, icing of the magnitude described by the pilots of NW flight 272 would have produced strong visual cues, and it is likely that the pilots would have commented on such a rapid accumulation, had it occurred. The accident airplane's CVR did not record any flightcrew comments about ice accumulation or the need to activate the leading edge deicing boots during the last 5 minutes of the accident flight; this is consistent with an ice accumulation that was either not observed by the pilots or that was observed but considered to be unremarkable.

Use of Deice/Anti-ice Equipment

The Safety Board attempted to determine whether the airplane's ice protection systems were operated during the accident airplane's descent and approach to DTW. CVR information showed that when the pilots performed the descent checklist at 1547, they confirmed that the airplane's "standard seven" anti-ice systems were activated and activated the windshield heat and the propeller deice system.[13] This was consistent with guidance contained in Comair's EMB-120 Flight Standards Manual (FSM), which stated that anti-ice systems should be activated "before flying into known icing conditions" to prevent ice accumulation on the affected surfaces. Comair's EMB-120 FSM defined icing conditions as existing "when the OAT [outside air temperature] is +5° C or below and visible moisture in any form is present (such as clouds, rain, snow, sleet, ice crystals, or fog with visibility of one mile or less)."

For years, airplane manufacturers have incorporated leading edge deicing boots in the design of airplanes that are to be certificated for operation in icing conditions; the purpose of deicing boots is to shed the ice that accumulates on protected surfaces of the airframe. Over the years, leading edge deicing boots have demonstrated their effectiveness to operators and pilots by keeping the wing and tail leading edges relatively clear of aerodynamically degrading ice accumulations, to the point that operators and pilots have become confident that the airplanes can be flown safely in icing conditions as long as the airplane's deicing boots are operated (and functioning) properly. However, based on problems with earlier deicing boot designs (which used larger tubes and lower pressures, resulting in slower inflation/deflation rates), manufacturers, operators, and pilots developed the belief that premature activation of the leading edge deicing boots could (as cautioned in Comair's EMB-120 FSM) "result in the ice forming the shape of an inflated de-ice boot, making further attempts to deice in flight impossible [ice bridging]." Thus, at the time of the accident, Comair's (and most other EMB-120 operators') guidance indicated that pilots should delay activation of the leading edge deicing boots until they observed ¼ inch to ½ inch ice accumulation, despite Embraer's FAA and Centro Tecnico Aeroespacial of Brazil (CTA) approved EMB-120 Airplane Flight Manual (AFM) revision 43, which indicated that pilots should activate the leading edge deicing boots at the first sign of ice accumulation.

[13] Although Embraer's nomenclature identifies the propeller ice protection mechanism as a deicing system, it functions as an anti-icing system because it is activated before ice accumulates on the airframe.

The pilots' activation of the propeller and windshield ice protection systems when the airplane entered the clouds would indicate that they were aware that the airplane was operating in icing conditions. If they had activated the leading edge deicing boots, at least some of the airplane's degraded performance would have been restored. However, even if the pilots observed any of the thin, rough ice accretion that likely existed before the loss of control, they probably would not have activated the deicing boots because Comair's guidance to its pilots advised against activating the deicing boots until they observed a thicker ice accumulation. Therefore, based on CVR information and on the steady degradation of airplane performance that was clearly uninterrupted by leading edge deicing boot activation, the Safety Board concludes that, consistent with Comair's procedures regarding ice protection systems, the pilots did not activate the leading edge deicing boots during their descent and approach to the Detroit area, likely because they did not perceive that the airplane was accreting significant (if any) structural ice.

During the postaccident (November 1997) Airplane Deicing Boot Ice Bridging Workshop, information regarding recent icing tunnel and flight test research into the ice bridging phenomenon was disseminated and discussed among industry personnel. The recent research revealed that modern turbine-powered airplanes, with their high-pressure, segmented pneumatic deicing boots, are not at risk for ice bridging.[14] However, in April 1996 when Embraer issued (FAA- and CTA-approved) revision 43 to the EMB-120 AFM, the procedure it recommended—activation of the leading edge deicing boots at the first sign of ice accretion—was not consistent with traditional industry concerns about ice bridging. According to the FAA's EMB-120 Aircraft Certification Program Manager, when the EMB-120 AFM revision was proposed by Embraer in late 1995, the deicing boot procedural change was very controversial and generated numerous discussions among FAA and industry personnel. The FAA's EMB-120 Aircraft Certification Program Manager stated that the aircraft evaluation group personnel involved in the discussions about the six EMB-120 icing-related events, the EMB-120 in-flight icing tanker tests, and the deicing boot procedural change were initially resistant to the deicing boot procedural change because of the perceived potential for ice bridging.

The Safety Board notes that during the winter of 1995/1996, senior Comair personnel (and representatives from other EMB-120 operators) were involved in numerous meetings and discussions regarding the six preaccident icing-related events and that they subsequently received Embraer's Operational Bulletin 120-002/96 and revision 43 to the EMB-120 AFM, with its controversial deicing boot procedural change. Although these discussions and documents apparently heightened senior Comair personnel's awareness and concern about EMB-120 operations in icing conditions (as evidenced by the December 1995 interoffice memo, entitled "Winter Operating Tips," and the October 1996 flight standards bulletin 96-04, entitled "Winter Flying Tips"), until the (postaccident) ice bridging workshop, there was insufficient information available to allay the company's concerns regarding the perceived hazards of ice bridging. Because Comair management personnel were still concerned that ice bridging was a problem for modern turbopropeller-driven airplanes, at the time of the accident, the company's deicing boot activation procedures had not been revised in accordance with AFM revision 43. The Safety Board recognizes the concerns regarding ice bridging that Comair had at the time of the accident

[14] It is important to note that ice bridging may still be a potential hazard for airplanes with older technology deicing boots that have slower inflation/deflation rates.

(before the ice bridging workshop) and notes that the FAA had not mandated incorporation of the procedural revision or engaged in discussions with EMB-120 operators/pilots regarding the merit of the procedural change. Apparently, Comair was not the only EMB-120 operator with concerns regarding the deicing boot procedural change because the air carriers' records indicated that at the time of the accident, only two of seven U.S.-based EMB-120 operators had incorporated the revision into its procedural guidance. However, the Board is concerned that Comair's EMB-120 pilots did not have access to the most current information regarding operating the EMB-120 in icing conditions.

According to EMB-120 pilots from Comair and the Air Line Pilots Association (ALPA), their discussions with other EMB-120 flightcrews indicate that the procedural change is still a controversial issue, despite the information revealed during this accident investigation and at the November 1997 Airplane Deicing Boot Ice Bridging Workshop. This illustrates how thoroughly ingrained the ice bridging concept was in pilots and operators and the importance of an ice bridging pilot education program. Therefore, a thin, yet performance-decreasing type of ice (similar to that likely accumulated by Comair flight 3272) can present a more hazardous situation than a 3-inch ram's horn ice accumulation because it would not necessarily prompt the activation of the boots. Based on this information, the Safety Board concludes that the current operating procedures recommending that pilots wait until ice accumulates to an observable thickness before activating leading edge deicing boots results in unnecessary exposure to a significant risk for turbopropeller-driven airplane flight operations. Based primarily on concerns about ice bridging, pilots continue to use procedures and practices that increase the likelihood of (potentially hazardous) degraded airplane performance resulting from small amounts of rough ice accumulated on the leading edges.

The Safety Board is aware that the FAA, NASA, and ALPA plan to organize an industry-wide air carrier pilot training campaign to increase pilots' understanding of the ice bridging phenomenon and safe operation of deicing boots. Unfortunately, according to NASA personnel, the training program has not yet begun because the FAA is still developing its position based on information from the Ice Bridging Workshop. The Safety Board appreciates the FAA's intention to initiate the development of ice bridging training and its desire to ensure that the training is as thorough and accurate as possible; however, the Board is concerned that the planned training is being delayed. Further, the planned training primarily targets air carrier pilots, and the Board considers it important that the information be disseminated to all affected pilots/operators. The Safety Board is concerned that if nonair carrier pilots and operators do not receive the training, they may operate turbopropeller-driven airplanes in icing conditions using deicing boot procedures that result in less safe flight operations. A training program that reaches only a limited part of the pilot population may not be sufficient to eliminate the pervasive beliefs regarding the potential for ice bridging in turbopropeller-driven airplanes.

Therefore, the Safety Board believes that NASA should (with the FAA and other interested aviation organizations) organize and implement an industry-wide training effort to educate manufacturers, operators, and pilots of air carrier and general aviation turbopropeller-driven airplanes regarding the hazards of thin, possibly imperceptible, rough ice accumulations, the importance of activating the leading edge deicing boots as soon as the airplane enters icing conditions (for those airplanes in which ice bridging is not a concern), and the importance of maintaining minimum airspeeds in icing conditions. The Safety Board encourages NASA and the FAA to expedite this training effort.

It is important to note that although leading edge deicing boots are useful in minimizing the adverse affects of ice accumulation on an airplane's protected surfaces, activation of deicing boots does not result in a completely clean boot surface; some residual ice remains on the deicing boot after it cycles, and intercycle ice accumulates between deicing boot cycles (on the EMB-120, during the 54-second or 174-second intervals, depending on the mode of boot operation selected). Icing tunnel tests indicate that when the deicing boots are activated early, the initial deicing boot cycle leaves a higher percentage of residual ice than it would with delayed deicing boot activation. However, when the deicing boots remained operating during the remainder of the ice encounter, subsequent deicing boot cycles resulted in a wing leading edge about as clean as would occur with delayed boot activation.

The FAA/UIUC wind tunnel tests revealed that even a thin, sparse (5 percent to 10 percent density ice coverage) amount of rough ice accumulation over the leading edge deicing boot coverage area resulted in significant aerodynamic degradation. This information raises questions about the effectiveness of leading edge deicing boots when dealing with this type of ice accumulation, especially considering a B.F. Goodrich estimation that a good, effective deicing boot shed leaves about 20 percent of the accumulated ice on the boots. The sparse ice coverage observed during the first 30 to 60 seconds of exposure time in some of NASA's icing tunnel test conditions (and which could occur between deicing boot cycles) was estimated by observers to be about 10 percent. This combined research indicates that it is possible for a hazardous situation to occur even if pilots operate the deicing boots early and throughout the icing encounter. The Westair flight 7233 incident, in which uncommanded roll and pitch excursions occurred despite the fact that the pilots stated that they had activated the leading edge deicing boots and selected the heavy boot operation mode,[15] may be an example of such a hazardous situation.

In addition, a hazardous situation may develop even if deicing boots are operated throughout an icing encounter as a result of ice accretions on an airplane's unprotected surfaces, such as aft of the deicing boots. The B.F. Goodrich impingement study, NASA's LEWICE calculations, and NASA IRT tests indicated that a light accretion may occur on the unprotected lower wing surfaces aft of the deicing boot on the EMB-120. However, Embraer representatives stated that such an ice accretion would result in only a trace of ice accumulating aft of the deicing boots and would have a minimal aerodynamic penalty in drag only. Although there was no evidence of ice accretion aft of the deicing boot during the EMB-120 certification natural icing tests and it was not possible to determine whether the accident airplane's ice accretion extended aft of the deicing boot coverage, it is possible that ice accretion on the unprotected surface aft of the deicing boot could exacerbate a potentially hazardous icing situation.

[15] According to the pilots of Westair flight 7233, they were aware that they were operating in "icing conditions;" they stated that they observed ice accumulating on the airplane and had activated the leading edge deicing boots when the airplane entered the clouds during their departure.

Based on icing and wind tunnel research and information from the Westair incident, the Safety Board concludes that it is possible that ice accretion on unprotected surfaces and intercycle ice accretions on protected surfaces can significantly and adversely affect the aerodynamic performance of an airplane even when leading edge deicing boots are activated and operating normally. Thus, pilots can minimize (but not always prevent) the adverse effects of ice accumulation on the airplane's leading edges by activating the leading edge deicing boots at the first sign of ice accretion. It is not clear what effect residual ice/ice accretions on unprotected nonleading edge airframe surfaces have on flight handling characteristics. Because not enough is known or understood about icing in general, and especially about the effects of intercycle and residual ice, the Safety Board believes that NASA should (with the FAA and other interested aviation organizations) conduct additional research to identify realistic ice accumulations, to include intercycle and residual ice accumulations and ice accumulations on unprotected surfaces aft of the deicing boots, and to determine the effects and criticality of such ice accumulations; further, the information developed through such research should be incorporated into aircraft certification requirements and pilot training programs at all levels.

Therefore, the National Transportation Safety Board makes the following recommendations to the National Aeronautics and Space Administration:

> With the Federal Aviation Administration and other interested aviation organizations, organize and implement an industry-wide training effort to educate manufacturers, operators, and pilots of air carrier and general aviation turbopropeller-driven airplanes regarding the hazards of thin, possibly imperceptible, rough ice accumulations, the importance of activating the leading edge deicing boots as soon as the airplane enters icing conditions (for those airplanes in which ice bridging is not a concern), and the importance of maintaining minimum airspeeds in icing conditions. (A-98-107)

> With the Federal Aviation Administration and other interested aviation organizations, conduct additional research to identify realistic ice accumulations, to include intercycle and residual ice accumulations and ice accumulations on unprotected surfaces aft of the deicing boots, and to determine the effects and criticality of such ice accumulations; further, the information developed through such research should be incorporated into aircraft certification requirements and pilot training programs at all levels. (A-98-108)

Chairman HALL, Vice Chairman FRANCIS, and Members HAMMERSCHMIDT, GOGLIA, and BLACK concurred in these recommendations.

By: Jim Hall
Chairman

National Transportation Safety Board

Washington, D.C. 20594

Safety Recommendation

Date: November 4, 1998
In reply refer to: A-98-112

Honorable Jane F. Garvey
Administrator
Federal Aviation Administration
Washington, D.C. 20591

On March 15, 1997, a Piper PA-31 airplane, operated by Cape Smythe Air Service as a scheduled commuter flight from Kivalina, Alaska, to Kotzebue, Alaska, landed with the left main landing gear (MLG) partially retracted at the Kotzebue Airport. None of the occupants was injured, and the airplane sustained minor damage.

Before landing, the pilot attempted to lower the landing gear; however, the landing gear did not extend normally, and the landing gear unsafe light illuminated in the cockpit. During a subsequent low pass over the airfield, ground personnel confirmed that the left MLG was not extended. Postincident examination revealed that a forward hinge on the left MLG inboard door had broken and disabled the door, preventing the gear from extending fully.

The PA-31 MLG inboard door is configured with two hinge assemblies that attach the door to the airplane, allowing the door to open during gear extension. There are two MLG inboard door hinge assemblies made for the PA-31: the original equipment hinge assembly (Piper part number (P/N) 46653-00) and an improved (thicker) hinge assembly (Piper P/N 47529-32). The improved hinge assembly consists of a 0.44-inch-thick, aluminum-forged hinge with two attachment angles.

The airplane had been operated for 13,988 hours in 17 years and 6 months of service and had been retrofitted with the improved hinge assemblies in 1988. The airplane had operated approximately 9,938 hours with the improved hinge assemblies before the hinge failure.

The National Transportation Safety Board's materials laboratory examined the fracture surfaces of the broken hinge. The examination revealed a fatigue crack that had emanated from multiple origins at the tip of the forged flash[1] on the inside curve portion of the hinge

[1] Excess metal that is forced out during the forging operation, between the upper and lower forging dies.

arm (see figure 1). The arm is subjected to cyclic loading during service, and the forging flash is a high-stress region of the hinge.

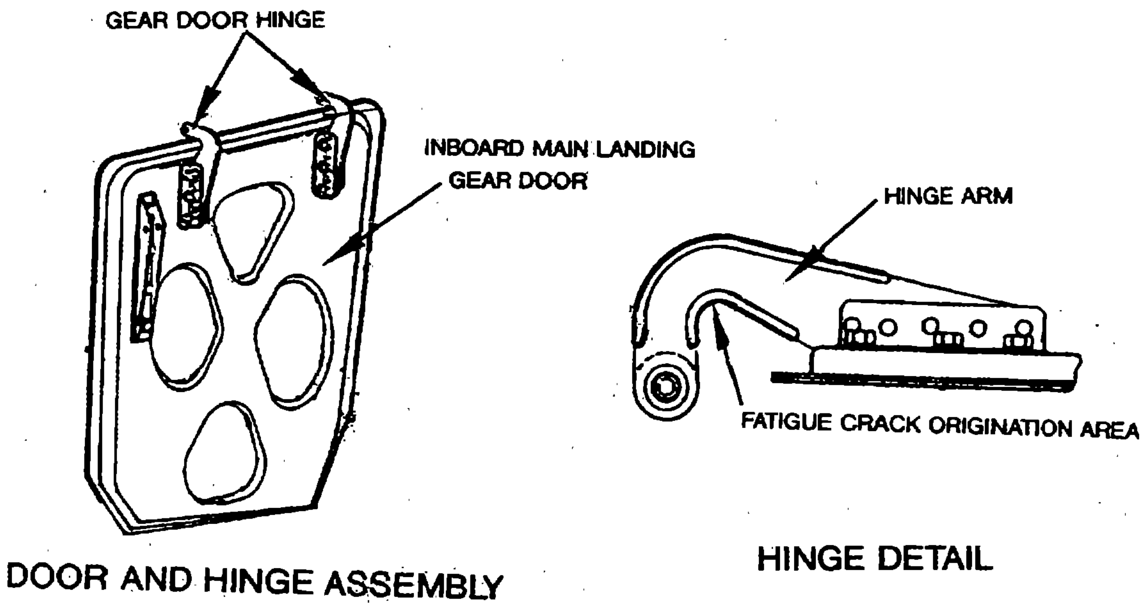


Figure 1. Piper PA-31 Main Landing Gear Door Assembly

In 1980, following several incidents of fatigue cracks in the original hinge, Piper Aircraft Corporation (now New Piper Aircraft, Inc.) issued Service Bulletin (SB) 682, which recommends inspection of the PA-31 MLG inboard door hinge assemblies and hinge attachment angles for cracks within the first 100 hours of operation or during the next scheduled inspection, whichever occurs first, and every 100 hours thereafter unless/until an acceptable replacement part is installed. The SB recommends that all cracked door hinges be replaced with the improved P/N 47529-32 hinge assemblies before further flight. Upon installation of the improved hinge assembly, repetitive inspection of the hinge assembly is not required. On December 19, 1980, the Federal Aviation Administration (FAA) issued Airworthiness Directive 80-26-05, mandating the actions specified in this SB.

However, despite these inspection and replacement procedures, service difficulty reports (SDR) indicate that since 1980 there have been at least 17 cracked or failed P/N 47529-32 hinge assemblies. Because experience has shown that the SDR system frequently underreports service failures, it is very likely that there have been other unreported events involving P/N 47529-32 hinge assembly failures. For example, the Safety Board's materials laboratory has examined another P/N 47529-32 hinge that separated because of fatigue cracking but there was no SDR report of the incident.

The Safety Board is concerned that the improved P/N 47529-32, PA-31 MLG inboard door hinge assemblies are failing and that no requirement exists for their recurrent inspection. Piper has indicated its intent to design a new sheet-metal hinge assembly that will replace the

P/N 47529-32 hinge assembly to preclude further failures. Therefore, the Safety Board believes that the FAA should require PA-31 operators to conduct repetitive inspections for cracks of all Piper P/N 47529-32 MLG inboard door hinge assemblies until they are replaced by an improved MLG inboard door hinge assembly that is not prone to similar failures.

Therefore, the National Transportation Safety Board recommends that the Federal Aviation Administration:

> Require Piper PA-31 operators to conduct repetitive inspections for cracks of all Piper part number 47529-32 main landing gear (MLG) inboard door hinge assemblies until they are replaced by an improved MLG inboard door hinge assembly that is not prone to similar failures. (A-98-112)

Chairman HALL, Vice Chairman FRANCIS, and Members HAMMERSCHMIDT, GOGLIA, and BLACK concurred in this recommendation.

By: Jim Hall
Chairman

National Transportation Safety Board

Washington, D.C. 20594

Safety Recommendation

Date: November 30, 1998

In reply refer to: A-98-119 through -121

Honorable Jane F. Garvey
Administrator
Federal Aviation Administration
Washington, D.C. 20591

On April 11, 1997, the pilot of a single-seat Glaser-Dirks DG-300 glider, N70644, was killed after he lost control of the aircraft for undetermined reasons and crashed near Minden, Nevada. The National Transportation Safety Board's investigation found that the pilot had jettisoned the glider's canopy in an apparent attempt to parachute from the aircraft but that he was subsequently incapacitated when the canopy struck his forehead during the jettison sequence (the basis for these findings is discussed later in this letter). As a result, he remained with the aircraft and was found in the cockpit with his seat belt restraint system still fastened. The nearly horizontal flightpath of the jettisoned canopy caused it to strike the glider's T-tail, become impaled on the horizontal portion of the T-tail, and remain with the aircraft until ground impact. The glider was destroyed.

The canopy's emergency jettison release knob and pin-latch handle had both been pulled in accordance with the requirements for jettisoning outlined in the DG-300 Pilot's Operating Handbook. The handbook indicates that the jettisoned canopy will then be blown away by the oncoming airsteam.

In normal operation, the canopy is latched or unlatched at the aft end, and the front end of the canopy pivots about an airframe-mounted pivot assembly. Pulling the canopy's pin-latch handle withdraws the pin from the latch clevis and unlocks the canopy at the aft end. The canopy's latching pin, on the aft upper part of the canopy, and the latch clevis, on the aft upper part of the cockpit, were found intact and undamaged. Pulling the jettison release knob unlocks the front end pivot assembly and allows a small spring to push the front end of the canopy upward, away from the pivot plate. The Safety Board found that activating the release knob on the ground results in a positive release of the canopy from the pivot plate. However, the spring force does not result in significant upward travel of the front end of the canopy and, therefore, may be insufficient to ensure automatic in-flight separation of the canopy from the fuselage.

The left and right outboard horizontal sections of the glider's T-tail contained impact marks with black paint smears similar to the black paint on the interior of the canopy frame; the distance between the impact marks approximated the length of the canopy frame. There were several small punctures on the upper surface of the tail; one was round with red material, approximating the shape and color of the jettison release knob. Pieces of the canopy Plexiglas were found up to 300 yards from the glider's main wreckage.

According to the autopsy report, the pilot's face had several large lacerations and abrasions with minimal associated hemorrhage. No blood was observed anywhere on the pilot's face, but the autopsy report described a large bruise on the forehead as follows: "Covering the front of the forehead, almost paralleling the eyebrows, is a 10.0 x 6.0 cm area of confluent purple-gray abrasion superimposing contusion." This was the only contusion[1] noted anywhere on the pilot's head. The contusion was consistent with impact from a solid, hard object with a linear edge. The absence of bleeding, despite large lacerations to the pilot's face, indicates that his death upon ground impact was abrupt, resulting from blunt force trauma.

The contusion (bruise) on the pilot's forehead, however, required a finite period of time after the trauma was inflicted for the injury to accumulate blood. Moreover, blood to this area of the body could not have resulted from gravity flow but had to be provided under pressure. Therefore, the impact force causing the contusion had to have been inflicted before the ground impact that killed the pilot. This fact, together with the shape and location of the contusion, provides compelling evidence that the canopy frame struck the pilot on the forehead during the jettison sequence.

The DG-300 is manufactured in Germany by DG Flugzeugbau GmbH and is type certificated in that country in the utility category, according to Joint Airworthiness Requirements for Sailplanes and Powered Sailplanes (JAR-22).[2] However, the glider has not been type certificated in the United States but is currently imported, licensed, and operated in the experimental category. According to the manufacturer, jettison of the DG-300 canopy or the canopies on DG-100/200/400/600 series gliders (aircraft configured with a similar canopy and jettison mechanism) was not required to be demonstrated during the course of German certification. However, the manufacturer indicated that, during a flight test of a DG-600, jettison of the canopy became necessary during a spiral dive and was accomplished successfully without injury to the pilot.

Egress from the cockpit and jettisoning of the canopy are addressed in the following excerpts from JAR 22.807, Emergency Exit:

---

[1]. A contusion (bruise) signifies hemorrhage into the skin, the tissues under the skin, or both. It is usually the result of a blow or squeeze that crushes the tissues and ruptures blood vessels but does not break the skin.

[2] JAR-22 is based on the Federal Republic of Germany's national airworthiness code and was developed through the joint participation of several European countries.

> (a) The cockpit must be so designed that unimpeded and rapid escape in emergency situations during flight and on the ground is possible with the occupant wearing a parachute.
>
> (b) The opening, and where appropriate jettisoning, of each canopy or emergency exit must not be prevented by the presence of the appropriate aerodynamic forces and/or the weight of the canopy at speeds up to V_{df} or by jamming of the canopy with other parts of the sailplane. The canopy or emergency exit attachment fittings must be designed to permit easy jettisoning, where jettisoning is a necessary feature of the design.

Until recently, all Glaser-Dirks gliders imported into the United States, except for the DG-500 model, were certificated in the experimental category. However, the DG-100/400/500/800 models are now type certificated in the standard (utility) airworthiness category, and the Safety Board understands that the Federal Aviation Administration (FAA) has initiated a program aimed at eventual type certification of all Glaser-Dirks gliders in the standard airworthiness category. Even though the Safety Board concurs with the FAA's certification objectives, it is concerned about the extent to which jettison of the canopies of these gliders has been demonstrated for certification purposes. Although the jettison of a DG-600 canopy was apparently accomplished without incident, the Safety Board does not believe that this single event provides a sufficient technical basis for concluding that the canopy can be jettisoned successfully under all conditions throughout the complete airspeed and maneuver operating envelopes of these gliders. For example, flight at high angles of attack or sideslip, as in a spin, might significantly affect a canopy's jettison characteristics and its subsequent flightpath.

In connection with an evaluation of existing glider canopy jettisoning systems, the German Federal Ministry of Transport commissioned the 1991 study "Problems and Improvements of Canopy Jettisoning Systems" in which tests were performed with a glider mounted on the roof of an automobile. Details were presented of the motion and flightpath of the canopy, after its release in an emergency, as well as the influence of airspeed, angle of attack, sideslip, and raising of the front end of the canopy. The study concluded the following:

> It is clear that none of the existing mechanisms in today's gliders guarantee a problem-free jettisoning of the canopy and there is a high risk of injury to the pilot by the moving canopy. The main reason for this is the nose-down pitching and nose-inwards yawing moment on the canopy. This is due to the position of the center of pressure which is behind the center of gravity. This nose-down moment can be transformed into a nose-up pitching moment by a rear hinge between the top of the canopy and the fuselage. This hinge can take the form of a simple clasp. In such cases, the hinge must be released at an angle of approximately 40 degrees between the canopy and the cockpit. This simple improvement means that after the release, the canopy rotates with a nose-up pitching moment, separates quickly

> from the cockpit and passes high above the rudder. There is no risk of injury to the pilot.
>
> An automatic jettisoning assumes a raising of the front part. At low speeds and a low angle of attack, the raising does not initiate the separation of the canopy. For this reason, there should be two handles on the right and left frame of the canopy which the pilot can use to assist jettisoning. These handles should also be used to release the canopy. This is why there should be two handles in any canopy jettisoning system.

The relatively shallow, almost horizontal flightpath of the jettisoned canopy from N70644, causing it to strike both the pilot and the glider's T-tail, contrasts sharply with the study's test results based on a canopy with a rear hinge that releases from the cockpit at about 40°. For example, in one such test conducted at 70 knots, the canopy rotated upward around the hinge, separated from the fuselage at the proper angle, ascended steeply, and passed over the glider's tail at a height of about 13 feet.

There are about 88 aircraft of the DG-300/400/500/600/800 series currently operating in the United States. The Safety Board believes, based on the FAA's program to eventually certificate all Glaser-Dirks gliders in the standard airworthiness category, that the models and their numbers may increase significantly. Therefore, the Safety Board believes that the FAA should require DG Flugzeugbau GmbH to conduct testing of the canopy jettison system used on all Glaser-Dirks gliders certificated in the United States to determine the design changes, conditions, or limitations necessary to ensure that the canopies can be reliably jettisoned throughout the airspeed and maneuver operating envelopes of the aircraft without striking the pilot. The Safety Board also believes that the FAA should issue an airworthiness directive, applicable to all Glaser-Dirks gliders certificated in the United States in the standard airworthiness category, requiring the implementation of any appropriate design changes and/or operational procedures. Further, The Board believes that the FAA should issue a special airworthiness information bulletin, applicable to all Glaser-Dirks gliders certificated in the United States in the special (experimental) airworthiness category, advising owners of the need to implement any appropriate design changes and/or operational procedures.

Therefore, the National Transportation Safety Board recommends that the Federal Aviation Administration:

> Require DG Flugzeugbau GmbH to conduct testing of the canopy jettison system used on all Glaser-Dirks gliders certificated in the United States to determine the design changes, conditions, or limitations necessary to ensure that the canopies can be reliably jettisoned throughout the airspeed and maneuver operating envelopes of the aircraft without striking the pilot. (A-98-119)

Issue an airworthiness directive, applicable to all Glaser-Dirks gliders certificated in the United States in the standard airworthiness category, requiring the implementation of any appropriate design changes and/or operational procedures. (A-98-120)

Issue a special airworthiness information bulletin, applicable to all Glaser-Dirks gliders certificated in the United States in the special (experimental) airworthiness category, advising owners of the need to implement any appropriate design changes and/or operational procedures. (A-98-121).

Chairman HALL, Vice Chairman FRANCIS, and Members HAMMERSCHMIDT, GOGLIA, and BLACK concurred in these recommendations.

Jim Hall

By: Jim Hall
Chairman

National Transportation Safety Board
Washington, D.C. 20594

Safety Recommendation

Date: November 30, 1998

In reply refer to: A-98-122 through -124

Honorable Jane F. Garvey
Administrator
Federal Aviation Administration
Washington, D.C. 20591

On June 2, 1998, a Boeing 757-232 (B-757), N629DL, owned and operated by Delta Airlines, Inc., was damaged when its left off-wing emergency evacuation slide separated from the airplane during a scheduled flight operated under Title 14 Code of Federal Regulations Part 121 en route from LaGuardia Airport (LGA) to Cincinnati/Northern Kentucky International Airport (CVG). The pilot reported that during climbout from LGA he noticed the engine indication and crew alerting system (EICAS) light illuminate, indicating that the left off-wing slide door was open. The flight continued to CVG and landed without further incident. None of the occupants were injured.

After the airplane landed, a Delta Airlines mechanic performed a walk-around inspection. During the inspection he saw that the left off-wing emergency escape slide had separated from the airplane, the left side of the fuselage aft of the slide was damaged, the slide was missing, and the restraining hook that mounted to the slide platform was broken, which allowed the platform to over-rotate, causing damage to the wing and fuselage (see figure 1). The slide carrier, the platform, and the door latching tube remained with the airplane. Further inspection found significant damage to the left side of the fuselage aft of the trailing edge of the left inboard flap.

During its investigation of the B-757 off-wing escape slide, the National Transportation Safety Board found that Delta Airlines had performed a replacement of the left off-wing emergency escape slide 2 days before the incident. The two mechanics who replaced the slide stated that it was the first time they had replaced a B-757 off-wing slide. The mechanics stated that they referred to the B-757 maintenance manual, sections 25-65-00 and 25-65-01, and the placard on the inside of the maintenance access door while they replaced the slide.[1] One mechanic maneuvered the round yellow actuator handle that secures the off-wing emergency slide door within the slide compartment (see figure 2), and the other mechanic held the slide door closed (by sitting on the wing and pressing on the door with both his feet.) The mechanic who manipulated the round yellow actuator handle said it was difficult to ensure that the handle was in the full-

[1] Section 25-65-00 describes the operation of the B-757 off-wing escape system, and 25-65-01 describes the removal/installation of the B-757 off-wing escape slide pack.

down position, stating that "it took several attempts to move the actuator handle to the latched position." The mechanics stated that after the door was latched one mechanic ran his finger around the door to ensure it was closed, and then both mechanics checked the EICAS in the cockpit to ensure that the door was closed. One of the two mechanics said that he had received instructions on how to replace the slide about 4 or 5 years ago during a 2-week B-757 initial maintenance training class that provided instructions on all B-757 systems. The other mechanic had not yet received training on the B-757 off-wing escape slide replacement during his 3 months of employment at Delta.

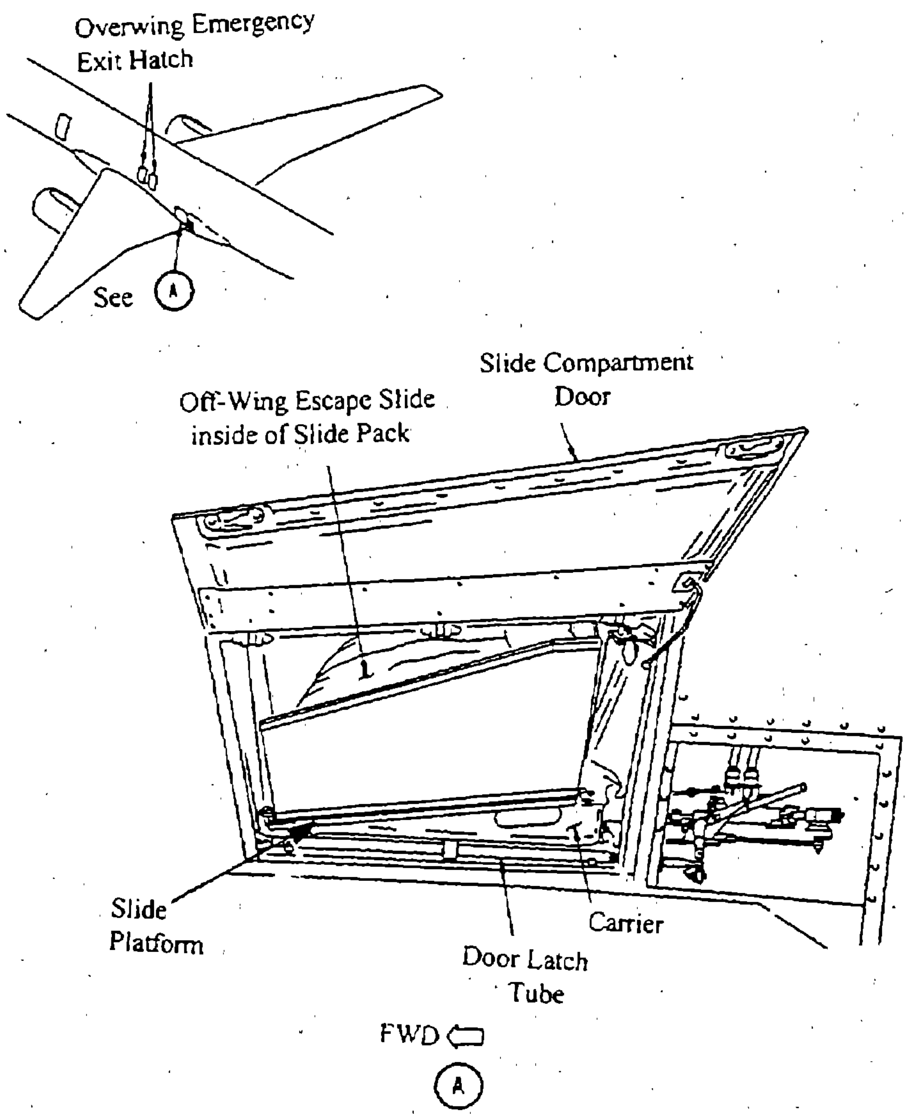


Figure 1.—B-757 Off-Wing Escape Slide Assembly

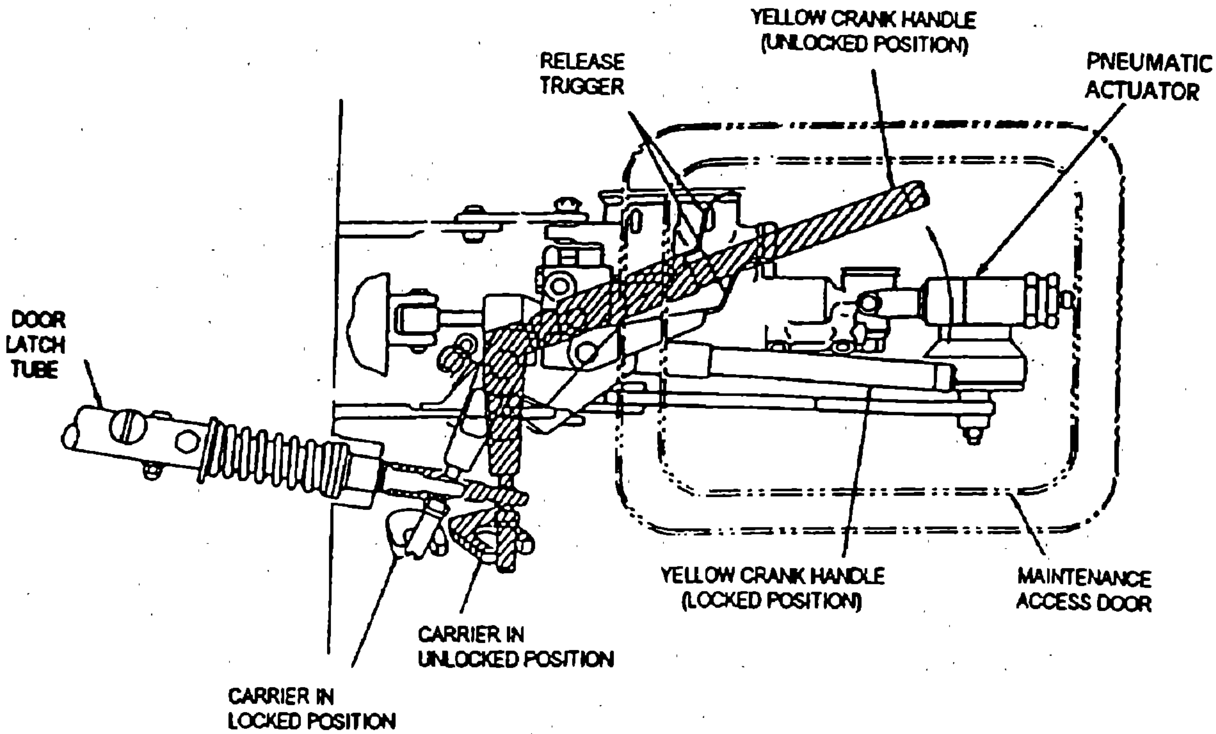


Figure 2.—B-757 Off-Wing Escape Slide Actuator Assembly

Previous In-flight Separations of Off-Wing Emergency Escape Slides

On October 16, 1997, a B-757, operated by United Airlines, Inc., was damaged when its left off-wing emergency evacuation slide separated from the airplane during a scheduled flight en route from Seattle, Washington, to Denver, Colorado. The captain stated to Safety Board investigators that as the airplane was rotated for liftoff, he noticed the EICAS light illuminate, indicating that the left wing slide door was open. The flight continued to Denver International Airport (DIA), and during its descent for landing, a flight attendant who was in the midcabin heard a loud noise on the left side of the airplane. The airplane landed without further incident at DIA, and none of the occupants were injured.

The Safety Board's investigation found that United had performed a routine replacement of the left off-wing emergency escape slide the evening before the incident. One of the two mechanics who replaced the slide that evening stated that it was only the second time in his 12-

year career with the airline that he had replaced a B-757 off-wing slide. He had replaced the first slide about 10 years earlier. The mechanic stated that when he replaced the slide the night before the incident, he had been outdoors (on the ramp) using a flashlight and had referred to the B-757 maintenance manual. The mechanic stated that he was not aware that there were instructions (which indicated the proper positioning of the yellow actuator handle that secured the off-wing emergency slide door within the slide compartment) on a placard inside the maintenance access door. The mechanic also stated that he had not received any formal training from Boeing or from United for installing the off-wing escape slide system and that he relied solely on the B-757 maintenance manual. The other mechanic stated that this was the first time that he had replaced a B-757 off-wing escape slide. He said that he had not received training on the B-757 off-wing escape slide replacement during his 11 years of employment at United.

On June 8, 1993, a B-757 left off-wing emergency escape slide deployed while United Airlines flight 382 was climbing through flight level 250. The captain heard an "explosive noise" followed by the airplane rolling sharply to the left.[2] The flightcrew declared an emergency and made an uneventful landing at Los Angeles International Airport, Los Angeles, California. A postincident inspection found that the left off-wing escape slide had deployed and had separated (at an unknown time) in flight. The Safety Board's investigation of the incident found that United had performed maintenance on the left off-wing escape slide before the flight.

Information on Servicing and Replacing the Off-Wing Emergency Escape Slide

The B-757 off-wing emergency escape slide system is located just above the trailing edge of each wing in the aft wing/body fairing and consists of a ramp/slide folded into a "slide pack" attached to a packboard and installed on a carrier assembly. To service the slide, a mechanic must first open the slide maintenance access door and release the trigger on a round yellow handle. The yellow handle actuates a pneumatic actuator, which unlatches the slide compartment door. The slide compartment door is locked in the closed position by lowering the yellow handle to its lowest position; this secures the door latch tube that is located along the lower edge of the slide compartment (see figure 2). A door sensor (micro switch) located on the aft edge of the door sill activates the "EMER DOORS" light on the cockpit overhead annunciator panel and displays the "L WING SLIDE" or "R WING SLIDE" EICAS message if either off-wing slide door opens more than 0.24 inch at its sensor switch.

Replacement of the slide requires that a mechanic remove the main landing gear wheel well access cover located directly beneath the slide carrier compartment to remove the bolts that secure the slide pack to the carrier. Also, the carrier has a locking pin that can only be viewed by a mechanic from the lower wheel well. When the slide's carrier is fully locked in place and the yellow crank handle is moved to the down and locked position, the locking pin should be fully engaged in the carrier's locking lug. The maintenance manual provides step-by-step guidance for the removal and installation of the B-757 off-wing emergency escape slide, and section 25-65-09

[2] For more detailed information, read Brief of Incident LAX93IA245 (enclosed).

recommends, "Push the handle down to its lowest position while you push inboard on the carrier to make sure the carrier is locked in the inboard position."

In-Service Activities Report and Service Bulletin History Regarding B-757 Off-Wing Escape Slides

In its September 14, 1993, B-757 In-Service Activities Report (SAR) No. 93-17, Boeing alerted operators of B-757s with off-wing slides (part number 93-17-2565-00) of the June 8, 1993, incident.[3] The SAR stated that the fuselage's paint had been scuffed in several large areas aft of the slide compartment door and on the leading edge of the left horizontal stabilizer. The SAR further stated that the aft latch of the airplane's left off-wing escape slide compartment door was only partially engaged, allowing the forward edge of the compartment door to open in the air stream and then to flex further into the air stream until it was forced open. The SAR further revealed that after the door had opened, the escape slide's carrier freely rotated out of its compartment, the slide release pin was pulled, and the escape slide unpacked and tore free from its packboard. Finally, the SAR stated that the B-757 maintenance manual's section 25-65-09 would be updated on September 20, 1993, to incorporate slide access door placard instructions and to clarify maintenance procedures for closing and properly locking the off-wing slide door.

On October 10, 1996, Boeing issued Service Bulletin (SB) 757-25-0182 to all operators of B-757 airplanes with off-wing escape slide systems through airplane production line position 727 (the 727th B-757 produced). The SB reported that two additional incidents had occurred since June 1993 in which air carrier operators had experienced the separation in flight of an off-wing emergency escape slide that resulted in damage to the airplane fuselage aft of the slide compartment.[4] All three incidents had occurred following maintenance. The SB stated that Boeing's analysis of the off-wing slide separations found three problems that induced the separations:

- difficulty in visually inspecting the forward edge of the slide compartment door to ensure that it is correctly latched,
- the aft location of the door's electrical sensor may not clearly indicate whether the forward edge of the slide compartment door is latched, and
- the incorrect installation of the lockbase retainer on the door latch tube, which can prevent locking the door latch tube in the latched position.

To remedy these problems, the SB provided instructions to replace the lockbase retainer and the bearing for the door's latch tube and to relocate the door's sensor forward on the slide compartment door.

---

[3] About 50 percent of the B-757 airplanes manufactured by Boeing are equipped with off-wing emergency escape slides.

[4] The two previous B-757 off-wing emergency escape slide incidents involved separations of right off-wing slides on a Continental Airlines B-757 on September 25, 1995, and a Boeing flight test B-757 airplane on November 15, 1995.

Since Boeing issued SB 757-25-0182, three other in-flight B-757 off-wing emergency escape slide separations have occurred following maintenance of the slides: the Delta Airlines N629DL on June 2, 1998; the United Airlines N581UA on October 16, 1997; and one involving an American Airlines B-757 on June 24, 1997. These airplanes had not been modified as directed by SB 757-25-0182. American Airlines subsequently painted a red stripe on the B-757 off-wing escape slide compartment door frames to help mechanics determine when the slide compartment door is properly positioned and latched.

On November 13, 1997, subsequent to the United and American separations, Boeing issued All-Operator Message M-7272-97-5654 to advise B-757 operators of the importance of incorporating SB 757-25-0182. The message informed operators of the importance of incorporating the SB at their earliest opportunity, of placing a new decal on the inside of the access door, of placing a paint stripe or tape on the lip of the maintenance access door (to show proper alignment and the locked position of the round yellow crank handle), and of removing the access panel from the container shroud in the main gear wheel well while a mechanic visually inspects that the carrier latch pin is fully engaged with the lock carrier fitting. Boeing reported that on May 20, 1998, the contents of the All-Operator Message were incorporated into its maintenance manuals.

The Safety Board commends all of the efforts made by Boeing; however, the Board is concerned that because these measures are not mandatory some operators may not perform the actions set forth in the SB. Therefore, the Safety Board believes that the Federal Aviation Administration (FAA) should issue an airworthiness directive (AD) to make compliance with Boeing SB 757-25-0182 mandatory to reduce the current potential for in-flight separation of the off-wing escape slides.

In a June 30, 1998, letter to the Safety Board, Boeing stated that it was designing the following three new system enhancements for the B-757 off-wing escape slides:

1.) installation of a bumper on the slide pack carrier to ensure it is pushed in far enough to be locked in place and to prevent movement of the carrier before actuation of the yellow crank handle,

2.) the addition of a witness mark on the lip of the maintenance access door frame that aligns with the yellow crank handle to ensure the handle is in the locked position, and

3.) the rewriting of the instructions on the placard on the inside of the maintenance access door to provide clear, concise direction to ensure the door is faired and latched prior to flight.

Boeing further reported that the three system enhancements are currently in the design phase and will be incorporated into the B-757 production line in December 1998. Boeing proposed that the B-757 fleet retrofit will be handled by a SB that will incorporate all three enhancements. Therefore, as a further safety measure, the Safety Board believes that the FAA should, upon release of the SB that incorporates the B-757 off-wing escape slide system enhancements currently in work by Boeing, issue an AD to mandate the incorporation of the improvements.

The Safety Board is concerned that mechanics may not be aware of Boeing's recently completed and proposed system enhancements on the B-757 off-wing escape slides. Further, because the B-757 off-wing escape slides are not frequently serviced or replaced, updated training would acquaint the mechanics with the recent changes and improvements to the B-757 off-wing escape slide system. Therefore, the Safety Board believes the FAA should issue a flight standards information bulletin to require that principal maintenance inspectors ensure that all mechanics are trained on the new off-wing escape slide system enhancements on the B-757.

Therefore, the National Transportation Safety Board recommends that the Federal Aviation Administration:

> Issue an airworthiness directive to make compliance with Boeing Service Bulletin 757-25-0182 mandatory to reduce the current potential for in-flight separation of the off-wing escape slides. (A-98-122)
>
> Upon release of the service bulletin that incorporates the B-757 off-wing escape slide system enhancements currently in work by Boeing, issue an airworthiness directive to mandate the incorporation of the improvements. (A-98-123)
>
> Issue a flight standards information bulletin to require that principal maintenance inspectors ensure that all mechanics are trained on the new off-wing escape slide system enhancements on the B-757. (A-98-124)

Chairman HALL, Vice Chairman FRANCIS, and Members HAMMERSCHMIDT, GOGLIA, and BLACK concurred in these recommendations.

By: Jim Hall
Chairman

Enclosure

National Transportation Safety Board
Washington, D.C. 20594

Brief of Incident

Adopted 08/01/1994

LAX93IA245
FILE NO. 5028 | 06/08/93 | LOS ANGELES,CA | AIRCRAFT REG. NO. N540UA | TIME (LOCAL) - 10:59 PDT

MAKE/MODEL - BOEING 757-222
ENGINE MAKE/MODEL - P & W 2037
AIRCRAFT DAMAGE - Minor
NUMBER OF ENGINES - 2

	FATAL	SERIOUS	MINOR/NONE
CREW	0	0	13
PASS	0	0	184

OPERATING CERTIFICATES - Flag carrier/domestic
NAME OF CARRIER - UNITED AIRLINES
TYPE OF FLIGHT OPERATION - Scheduled
- Domestic
- Passenger

REGULATION FLIGHT CONDUCTED UNDER - 14 CFR 121

LAST DEPARTURE POINT - Same as Incident
DESTINATION - DENVER,CO

AIRPORT PROXIMITY - Off airport/airstrip

CONDITION OF LIGHT - Daylight

WEATHER INFO SOURCE- Pilot

BASIC WEATHER - Visual (VMC)
LOWEST CEILING - None
VISIBILITY - 0050.000 SM
WIND DIR/SPEED - Unk/Nr
TEMPERATURE (F) - Unk/Nr
OBSTR TO VISION - None
PRECIPITATION - None

PILOT-IN-COMMAND AGE - 58

CERTIFICATES/RATINGS
Airline transport
Single-engine land, Multiengine land
INSTRUMENT RATINGS
Airplane

FLIGHT TIME (Hours)

TOTAL ALL AIRCRAFT - 18400
LAST 90 DAYS - Unk/Nr
TOTAL MAKE/MODEL - Unk/Nr
TOTAL INSTRUMENT TIME - Unk/Nr

The aircraft was climbing through 25,000 feet in light turbulence when the crew felt two jolts and heard a loud explosive noise followed by a sharp roll to the left. A visual inspection revealed that the left overwing emergency escape slide deployed and separated in flight. The crew returned to Los Angeles and made an uneventful landing. Post incident examination revealed that the slide compartment door was unlatched and open, and, the adjacent maintenance access door was open, with the latching handle in the unlocked position. The flight prior to the incident one had experienced two EICAS warning messages concerning the left overwing slide door. After landing, maintenance personnel accessed the compartment, cleaned a proximity switch then functionally tested the system. The flight was then dispatched with no open items. The maintenance closing procedure in effect at the time of the incident called for one mechanic to hold the bottom corners of the 33 inch wide slide door closed while manipulating the latching handle in a maintenance access door 12 inches aft of the slide door. The procedure has since been changed to require two mechanics, one to hold the door closed while the second manipulates the latching handle.

LAX93IA245
FILE NO. 5028 06/08/93 LOS ANGELES,CA AIRCRAFT REG. NO. N540UA TIME (LOCAL) - 10:59 PDT

Occurrence# 1 MISCELLANEOUS/OTHER
Phase of Operation CLIMB - TO CRUISE

Findings
1. - MISC EQPT/FURNISHINGS,SLIDES - UNLATCHED
2. - MAINTENANCE,ALIGNMENT - INADEQUATE - COMPANY MAINTENANCE PERSONNEL
3. - PROCEDURE INADEQUATE - MANUFACTURER

The National Transportation Safety Board determines that the probable cause(s) of this incident was: the inadvertent deployment of an overwing emergency excape slide due to the inadequate latching of the slide compartment door following access by maintenance personnel. A factor in the accident was the inadequate door closing procedure specified by the manufacturer and the airline in the maintenance instructions.

National Transportation Safety Board

Washington, D.C. 20594

Safety Recommendation

Date: November 30, 1998

In Reply Refer To: H-98-43 through -46

Honorable Rodney E. Slater
Secretary
U.S. Department of Transportation
Washington, D.C. 20590

Recently, the National Transportation Safety Board has investigated transit bus accidents in Normandy, Missouri; Cosmopolis, Washington; New York, New York; and Nashville, Tennessee.[1] The Normandy, New York, and Nashville accidents exposed various operational deficiencies such as unqualified drivers, drivers with hazardous medical conditions, inadequate maintenance practices, and the operation of buses with mechanical defects. The Cosmopolis accident revealed that certain laws and school transportation safety operational practices are not applicable to transit operations.[2] Had these deficiencies been found during other types of bus operations,[3] which fall under Federal and State government safety regulations, sanctions could have been imposed, such as assessing fines, taking the buses out of service, or suspending the company operations. However, no such Federal regulations are in place for transit buses. Of the four accident locations, only New York conducts some type of oversight of transit bus operations.

---

[1]For more detailed information, read Highway Accident Summary Report—*Transit Bus Collision with Pedestrians, Normandy, Missouri, June 11, 1997* (NTSB/HAR-98/01/SUM); Highway Accident/Incident Summary Report—*Collision with a Pedestrian by a Utility Truck near Cosmopolis, Washington, November 26, 1996* (NTSB/HAR-97/01/SUM); and National Transportation Safety Board Accident Investigations—*Transit Bus Collision with Pedestrian in New York City, New York, October 2, 1997* (HWY98FH019) and *Transit Bus Collision with Multiple Vehicles in Nashville, Tennessee, August 31, 1998* (HWY98FH042).

[2]Laws that require traffic to stop for school buses that are loading or discharging students are not in effect for transit buses. A transit bus is neither painted yellow, equipped with stop arms or bars, nor required to have its driver ensure that children are safely out of the roadway after exiting the bus.

[3]Interstate motor coach or charter buses.

As a result of the Normandy, Missouri, accident in which four pedestrians were killed and three injured, the Safety Board held a public hearing on March 3 and 4, 1998, to determine the extent of transit bus safety oversight. During the public hearing, witnesses representing State and Federal government agencies testified as well as representatives from several transit agencies, member service organizations, and State associations. The participants in the hearing discussed transit agency self-regulation, the extent of Federal and State safety oversight, accident data, pupil transportation, and driver selection and qualification.

After the Safety Board conducted several accident investigations involving transit buses and held the public hearing on transit bus safety in March 1998, it found that substantial safety deficiencies and little Federal or State government safety oversight exist within the transit bus industry. The Safety Board understands that the Federal Government is spending $6.34 billion to subsidize the operation of transit agencies;[4] yet, its safety oversight of transit bus operations is essentially nonexistent. The public expects that transit bus operations, whether publicly owned or subsidized, are safe.[5]

The above four accidents, which occurred in different parts of the country, highlight significant safety problems in the transit bus industry. The Safety Board is concerned that the Federal Government provides significant funding for public transit operations without ensuring adequate safety oversight. Federal Transit Administration (FTA) officials stated that they have three methods to assess the safety of the transit bus agencies that receive Federal funding. However, none of these methods provides a comprehensive assessment of transit bus safety throughout the country or a remedy for any of the problems that may exist.

One method is the sharing of safety information among transit agencies, which enables the agencies to perform self-assessments of their operational safety. This information is composed of data that are reported annually to the FTA by each transit agency receiving Federal funds. Unfortunately, some of the data may be 2 years old before it is available and may not be accurate or sufficient for transit bus agencies to thoroughly compare the safety of their operations with that of other agencies.

Another method containing a safety component is a program of triennial reviews, which are employed to measure the responsible use of Federal funds. The reviews were legislated by the U.S. Congress because of a concern that the FTA was not adequately monitoring the use of Federal funds. The FTA hires contractors to perform the triennial reviews of all (about 550 urban) transit agencies directly receiving Federal funds. (The other transit agencies receive Federal funding administered through the States.) The Office of Oversight within the Office of Program Management oversees the contractors. The Office of Safety and Security does not participate in the triennial review process.

[4]Of this amount, over $2.5 billion is provided for transit bus operations.

[5]For more detailed information, read Special Investigation Report—*Transit Bus Safety Oversight* (NTSB/SIR-98/03).

In conducting the reviews, contractors go to each transit agency and ask questions to ascertain whether the transit agency is performing certain required functions. Subject questions include whether the agency is in compliance with the American Disabilities Act, the Buy America law, the Service Equity laws, and the Disadvantaged Business Enterprise regulations; few questions concern transportation safety programs. The contractor makes no assessment of the effectiveness of the safety programs at the transit agency. Transit funding is not dependent on the results of the responses to the safety questions posed during the triennial review.

According to the FTA, its primary role is to provide capital for operational assistance to transit programs. The Safety Board is concerned that funding is occurring without any reasonable checks to ensure that Federal funds are being used in the public's best interest and that the public's safety on transit buses is not being compromised. The FTA considers its primary responsibility to be the disbursement of Federal funds and, as such, engages in a cooperative partnership with the transit industry. The FTA stated at the public hearing that it has traditionally looked either to State regulation, if it exists, or to self-regulation by the transit industry to safeguard the public's use of these transportation systems.

The FTA has no method to ensure safety, which is specifically focused on operations within transit bus agencies. For the FTA to have an effective safety oversight program, it would need to ensure that 1) safety plans are required and implemented, 2) the Office of Safety and Security is included in the triennial review process to ensure that safety plans are complete and in use for all fund-recipient operations, and 3) all safety deficiencies are corrected within transit bus agencies. The Safety Board concludes that the FTA is unable to identify situations that may lead to unsafe conditions on buses for the traveling public or to resolve any unsafe conditions because of a lack of effective safety oversight and enforcement. The Safety Board, therefore, believes that the DOT should develop and implement an oversight program to assess and ensure the safety of transit bus operations that receive Federal funding.

Before 1990, the FTA did not collect data on transit bus operations; only data on rail rapid transit were collected. Currently, however, all public transit agencies receiving Federal assistance under the FTA's formula program must report accident data to retain eligibility for Federal funds. The FTA accident data only contain the number of fatalities, injuries, and incidents in the given year;[6] and, therefore, this accident data can only be used to establish numeric trends in the occurrences of fatalities that result from noncollisions and from collisions with vehicles, objects, and people. The FTA requires the reporting of transit bus incidents that meet the following criteria:

- any event involving property damage exceeding $1,000;
- any incident requiring medical treatment of a passenger or an employee, either on site or in a hospital; or
- any fatality resulting from the event occurring within 30 days.

---

[6]The FTA plans to publish a Notice of Proposed Rulemaking to expand the data fields collected.

The FTA obtains summary accounts from the transit operators, who report data for their previous fiscal year, which vary across transit agencies. The FTA, however, reports the data by calendar year. By the time the FTA collects and collates the data for a report, it is almost 2 years old. Because of the different reporting timetables allowed by the FTA, accident data from transit agencies are routinely being discounted from the FTA statistical database.

The National Highway Traffic Safety Administration (NHTSA) Fatality Analysis Reporting System (FARS) only collects accident data that involve fatalities. In the FARS database, an accident must involve a motor vehicle traveling on a roadway open to the public and result in the death of a person, either an occupant of a vehicle or a nonmotorist, within 30 days of the accident. FARS is based on police reports, medical examiner and death records, and other reports, which are related by calendar year. Each accident maintained in FARS has more than 100 coded data elements that characterize the accident, the vehicles, and the people involved in fatal accidents.

In 1996, the FARS database reported 126 fatalities in transit bus collisions (5 of these were passengers on a transit bus; the others were either pedestrians or people in other vehicles). That same year, the FTA reported 83 fatalities in transit bus accidents (it is impossible to determine where the fatal injuries occurred based on the FTA data). The FTA has maintained that the number of transit bus fatalities has steadily decreased; however, the FARS data indicate that the number of fatalities has not decreased. The differences in the number of fatalities may be explained by the differences in the databases.

The FTA fatality data also are not as comprehensive as FARS data and lack a tracking program for injury severity, contributing factors, vehicle actions, driver actions, or other safety-related factors. Still, the FTA data provide more accurate injury counts for accidents than do the FARS data. FARS does not present all injury data, only that injury data for people involved in a fatal accident.

Before 1984, the Federal Highway Administration (FHWA) had the authority to conduct safety oversight of transit bus operations. In 1984, the U.S. Congress passed the Motor Carrier Safety Act, which specifically exempted passenger carrier operations that were part of Federal, State, or quasi-public operations. In May 1988, the FHWA issued a rulemaking, to the same effect as the 1984 act, including the same exemptions in the Federal Motor Carrier Safety Regulations.[7] The FHWA currently has no authority to perform any safety reviews or inspections of transit bus operations.

[7]Title 49 *Code of Federal Regulations* Part 390.3(f)(2) exempts, with the exception of the recordkeeping requirements of Part 390.15, transportation performed by the Federal Government, a State or any political subdivision of a State, or an agency, established under a compact between States that has been approved by the U.S. Congress.

The FHWA collects bus accident data from State and local enforcement agencies. However, FHWA representatives testified during the hearing that approximately one-third of this data is not reported to the database by State or local enforcement personnel and that the data do not distinguish between transit and other types of buses.

As discussed above, the reporting and collection system that the FTA is using lends itself to discrepancies in the FTA final reports. The FTA data also are of limited value, can be used only to identify numeric trends of transit bus accidents, and are not useable to identify the underlying causes of or contributing factors to these trends. Therefore, the Safety Board concludes that the accident data presented by the FTA, NHTSA, and the FHWA do not accurately portray the transit bus industry's safety record due to the data limitations of each and, in the case of the FTA, the lack of timeliness. In addition, the Safety Board concludes that the lack of accurate and sufficient data within the transit bus industry prevents a thorough assessment of transit bus safety. Consequently, the Safety Board believes that the DOT should collect accurate, timely, and sufficient data so that thorough assessments can be made relating to transit bus safety. Furthermore, the Safety Board believes that as part of the oversight program, the DOT should evaluate the collected data to identify the underlying causes of transit bus accidents that could lead to the identification of safety deficiencies at transit agencies.

Although safety programs at the Federal level are essentially nonexistent and the State programs vary, the American Public Transit Association (APTA) has developed two programs to provide for safe operations at its member transit agencies. However, these programs are not available to all transit agencies (only to APTA membership, which is less than 10 percent of all transit agencies) and have a fee associated with them.

APTA has drafted the Bus Safety Management Program (BSMP), a system safety program that will be applicable to transit bus operations, as well as the *Manual for the Development of Bus Transit System Safety Program Plans*. The BSMP is similar to the APTA rail rapid transit system safety program, on which the FTA State Safety Oversight of Rail Fixed Guideway Systems Program was modeled. The BSMP will help transit agencies set up a safety program in conformance with the *Manual for the Development of Bus Transit System Safety Program Plans*. APTA will then examine each system safety program on a triennial basis and evaluate whether the transit agency has: a system safety program plan that is in conformance with the APTA *Manual for the Development of Bus Transit System Safety Program Plans*; its system safety program plan fully implemented; and conducted an internal safety audit program to identify, track, and resolve safety program deficiencies. However, compliance with the safety oversight of operations will still be the responsibility of the individual transit agency even with the implementation of the BSMP.

In 1993, APTA conducted a survey of the hiring practices of various transit agencies because of concerns within the transit industry about the ratio of accident and employee-retention rates of newly hired drivers compared with experienced drivers. Over 100 agencies responded to the survey, resulting in the APTA conclusion that the then-existing recruiting and hiring

practices were extremely diverse. In December 1994, APTA published the final report *Bus Operator Selection System*[8] (BOSS), which details a selection system that could be adopted by a transit agency and allow the recruitment of drivers who would be more likely to maintain stable attendance and employment records. In addition to employment stability, according to APTA, this system would also reduce the accident rates typically experienced with new operators, as has been encountered by those transit agencies that evaluated the system.

Since its inception, BOSS has been implemented at 31 agencies, including the New York City Transit Authority, and numerous agencies are in the process of implementing this selection system. According to APTA testimony at the public hearing, program start-up requires a major commitment on the part of the transit agency to internally probe its processes and to involve its human resource and operations people in preparing for implementation. Additionally, the BOSS program has a cost factor associated with it for the ongoing support of the consultant who developed it. APTA believes that because of these factors, the BOSS program will probably require time to be universally accepted and applied but eventually all APTA transit agency members will use the program.

At the public hearing, the Community Transportation Association of America (CTAA) voiced its concern that the BOSS program primarily addresses the problems facing the APTA membership. The CTAA emphasized that New York City alone hires about 1,200 bus operators annually and the rural transit network nationwide totals only between 6,000 and 7,000 bus operators. The number difference in hiring demands results in different training and recruitment needs for smaller rural transit systems. The typical CTAA member employs a total of six busdrivers, whose employment involves low turnover and wages.[9] The CTAA also testified that because its members operate in rural areas, the labor market is limited and many of the operators believe that they are almost forced to hire the available drivers and then attempt to train them to be qualified safe bus operators.

While APTA has taken steps to ensure that uniform safety and qualifications will be applied to its member transit bus agencies, this only represents 10 percent of all transit agencies. Consequently, the Safety Board concludes that a model comprehensive safety program is not available for all transit bus agencies, only urban transit agencies that are members of APTA. Therefore, the Safety Board believes the DOT, APTA, the CTAA, and the American Association of State Highway and Transportation Officials, in cooperation, should develop a model comprehensive safety program(s) and provide it to all transit agencies.

Therefore, the National Transportation Safety Board recommends that the U.S. Department of Transportation:

> Develop and implement an oversight program to assess and ensure the safety of transit bus operations that receive Federal funding. (H-98-43)

---

[8]APTA contracted Landy Jacobs, Inc., a human resource consulting firm based in State College, Pennsylvania, to develop this project.

[9]Approximately 10 percent of the CTAA's membership only pay their busdrivers minimum wage.

Collect accurate, timely, and sufficient data so that thorough assessments can be made relating to transit bus safety. (H-98-44)

Evaluate the collected data, as part of the oversight program, to identify the underlying causes of transit bus accidents that could lead to the identification of safety deficiencies at transit agencies. (H-98-45)

Develop, in cooperation with the American Public Transit Association, the Community Transportation Association of America, and the American Association of State Highway and Transportation Officials, a model comprehensive safety program(s) and provide it to all transit agencies. (H-98-46)

Also, the Safety Board issued Safety Recommendations H-98-47 to the American Public Transit Association, H-98-48 to the Community Transportation Association of America, and H-98-49 to the American Association of State Highway and Transportation Officials. If you need additional information, you may call (202) 314-6441.

Chairman HALL, Vice Chairman FRANCIS, and Members HAMMERSCHMIDT, GOGLIA, and BLACK concurred in these recommendations.

Jim Hall

By Jim Hall
Chairman

National Transportation Safety Board

Washington, D.C. 20594

Safety Recommendation

Date: November 30, 1998

In Reply Refer To: H-98-47

Mr. William W. Millar
President
American Public Transit Association
1201 New York Avenue, N.W.
Washington, D.C. 20005

Recently, the National Transportation Safety Board has investigated transit bus accidents in Normandy, Missouri; Cosmopolis, Washington; New York, New York; and Nashville, Tennessee.[1] The Normandy, New York, and Nashville accidents exposed various operational deficiencies such as unqualified drivers, drivers with hazardous medical conditions, inadequate maintenance practices, and the operation of buses with mechanical defects. The Cosmopolis accident revealed that certain laws and school transportation safety operational practices are not applicable to transit operations.[2] Had these deficiencies been found during other types of bus operations,[3] which fall under Federal and State government safety regulations, sanctions could have been imposed, such as assessing fines, taking the buses out of service, or suspending the company operations. However, no such Federal regulations are in place for transit buses. Of the four accident locations, only New York conducts some type of oversight of transit bus operations.

[1]For more detailed information, read Highway Accident Summary Report—*Transit Bus Collision with Pedestrians, Normandy, Missouri, June 11, 1997* (NTSB/HAR-98/01/SUM); Highway Accident/Incident Summary Report—*Collision with a Pedestrian by a Utility Truck near Cosmopolis, Washington, November 26, 1996* (NTSB/HAR-97/01/SUM); and National Transportation Safety Board Accident Investigations—*Transit Bus Collision with Pedestrian in New York City, New York, October 2, 1997* (HWY98FH019) and *Transit Bus Collision with Multiple Vehicles in Nashville, Tennessee, August 31, 1998* (HWY98FH042).

[2]Laws that require traffic to stop for school buses that are loading or discharging students are not in effect for transit buses. A transit bus is neither painted yellow, equipped with stop arms or bars, nor required to have its driver ensure that children are safely out of the roadway after exiting the bus.

[3]Interstate motor coach or charter buses.

As a result of the Normandy, Missouri, accident in which four pedestrians were killed and three injured, the Safety Board held a public hearing on March 3 and 4, 1998, to determine the extent of transit bus safety oversight. During the public hearing, witnesses representing State and Federal government agencies testified as well as representatives from several transit agencies, member service organizations, and State associations. The participants in the hearing discussed transit agency self-regulation, the extent of Federal and State safety oversight, accident data, pupil transportation, and driver selection and qualification.

After the Safety Board conducted several accident investigations involving transit buses and held the public hearing on transit bus safety in March 1998, it found that substantial safety deficiencies and little Federal or State government safety oversight exist within the transit bus industry. The Safety Board understands that the Federal Government is spending $6.34 billion to subsidize the operation of transit agencies;[4] yet, its safety oversight of transit bus operations is essentially nonexistent. The public expects that transit bus operations, whether publicly owned or subsidized, are safe.[5]

Although safety programs at the Federal level are essentially nonexistent and the State programs vary, APTA has developed two programs to provide for safe operations at its member transit agencies. However, these programs are not available to all transit agencies (only to APTA membership, which is less than 10 percent of all transit agencies) and have a fee associated with them.

APTA has drafted the Bus Safety Management Program (BSMP), a system safety program that will be applicable to transit bus operations, as well as the *Manual for the Development of Bus Transit System Safety Program Plans*. The BSMP is similar to the APTA rail rapid transit system safety program, on which the FTA State Safety Oversight of Rail Fixed Guideway Systems Program was modeled. The BSMP will help transit agencies set up a safety program in conformance with the *Manual for the Development of Bus Transit System Safety Program Plans*. APTA will then examine each system safety program on a triennial basis and evaluate whether the transit agency has: a system safety program plan that is in conformance with the APTA *Manual for the Development of Bus Transit System Safety Program Plans*; its system safety program plan fully implemented; and conducted an internal safety audit program to identify, track, and resolve safety program deficiencies. However, compliance with the safety oversight of operations will still be the responsibility of the individual transit agency even with the implementation of the BSMP.

In 1993, APTA conducted a survey of the hiring practices of various transit agencies because of concerns within the transit industry about the ratio of accident and employee-retention rates of newly hired drivers compared with experienced drivers. Over 100 agencies responded to the survey, resulting in the APTA conclusion that the then-existing recruiting and hiring

---

[4]Of this amount, over $2.5 billion is provided for transit bus operations.

[5]For more detailed information, read Special Investigation Report—*Transit Bus Safety Oversight* (NTSB/SIR-98/03).

practices were extremely diverse. In December 1994, APTA published the final report *Bus Operator Selection System* (BOSS), which details a selection system that could be adopted by a transit agency and allow the recruitment of drivers who would be more likely to maintain stable attendance and employment records. In addition to employment stability, according to APTA, this system would also reduce the accident rates typically experienced with new operators, as has been encountered by those transit agencies that evaluated the system.

Since its inception, BOSS has been implemented at 31 agencies, including the New York City Transit Authority, and numerous agencies are in the process of implementing this selection system. According to APTA testimony at the public hearing, program start-up requires a major commitment on the part of the transit agency to internally probe its processes and to involve its human resource and operations people in preparing for implementation. Additionally, the BOSS program has a cost factor associated with it for the ongoing support of the consultant who developed it. APTA believes that because of these factors, the BOSS program will probably require time to be universally accepted and applied but eventually all APTA transit agency members will use the program.

At the public hearing, the Community Transportation Association of America (CTAA) voiced its concern that the BOSS program primarily addresses the problems facing the APTA membership. The CTAA emphasized that New York City alone hires about 1,200 bus operators annually and the rural transit network nationwide totals only between 6,000 and 7,000 bus operators. The number difference in hiring demands results in different training and recruitment needs for smaller rural transit systems. The typical CTAA member employs a total of six busdrivers, whose employment involves low turnover and wages.[6] The CTAA also testified that because its members operate in rural areas, the labor market is limited and many of the operators believe that they are almost forced to hire the available drivers and then attempt to train them to be qualified safe bus operators.

While APTA has taken steps to ensure that uniform safety and qualifications will be applied to its member transit bus agencies, this only represents 10 percent of all transit agencies. Consequently, the Safety Board concludes that a model comprehensive safety program is not available for all transit bus agencies, only urban transit agencies that are members of APTA.

Therefore, the National Transportation Safety Board recommends that the American Public Transit Association:

> Develop, in cooperation with the U.S. Department of Transportation, the Community Transportation Association of America, and the American Association of State Highway and Transportation Officials, a model comprehensive safety program(s). (H-98-47)

---

[6]Approximately 10 percent of the CTAA's membership only pay their busdrivers minimum wage.

In addition, the Safety Board issued Safety Recommendations H-98-43 through -46 to the U.S. Department of Transportation, H-98-48 to the Community Transportation Association of America, and H-98-49 to the American Association of State Highway and Transportation Officials.

The National Transportation Safety Board is an independent Federal agency with the statutory responsibility "to promote transportation safety by conducting independent accident investigations and by formulating safety improvement recommendations" (Public Law 93-633). The Safety Board is vitally interested in any action taken as a result of its safety recommendations. Therefore, it would appreciate a response from you regarding action taken or contemplated with respect to the recommendation in this letter. Please refer to Safety Recommendation H-98-47 in your reply. If you need additional information, you may call (202) 314-6441.

Chairman HALL, Vice Chairman FRANCIS, and Members HAMMERSCHMIDT, GOGLIA, and BLACK concurred in this recommendation.

Jim Hall

By: Jim Hall
Chairman

National Transportation Safety Board
Washington, D.C. 20594

Safety Recommendation

Date: November 30, 1998

In Reply Refer To: H-98-48

Mr. Dale Marsico
Executive Director
Community Transportation Association of America
1341 G Street, N.W.
Washington, D.C. 20005

Recently, the National Transportation Safety Board has investigated transit bus accidents in Normandy, Missouri; Cosmopolis, Washington; New York, New York; and Nashville, Tennessee.[1] The Normandy, New York, and Nashville accidents exposed various operational deficiencies such as unqualified drivers, drivers with hazardous medical conditions, inadequate maintenance practices, and the operation of buses with mechanical defects. The Cosmopolis accident revealed that certain laws and school transportation safety operational practices are not applicable to transit operations.[2] Had these deficiencies been found during other types of bus operations,[3] which fall under Federal and State government safety regulations, sanctions could have been imposed, such as assessing fines, taking the buses out of service, or suspending the company operations. However, no such Federal regulations are in place for transit buses. Of the four accident locations, only New York conducts some type of oversight of transit bus operations.

---

[1]For more detailed information, read Highway Accident Summary Report—*Transit Bus Collision with Pedestrians, Normandy, Missouri, June 11, 1997* (NTSB/HAR-98/01/SUM); Highway Accident/Incident Summary Report—*Collision with a Pedestrian by a Utility Truck near Cosmopolis, Washington, November 26, 1996* (NTSB/HAR-97/01/SUM); and National Transportation Safety Board Accident Investigations—*Transit Bus Collision with Pedestrian in New York City, New York, October 2, 1997* (HWY98FH019) and *Transit Bus Collision with Multiple Vehicles in Nashville, Tennessee, August 31, 1998* (HWY98FH042).

[2]Laws that require traffic to stop for school buses that are loading or discharging students are not in effect for transit buses. A transit bus is neither painted yellow, equipped with stop arms or bars, nor required to have its driver ensure that children are safely out of the roadway after exiting the bus.

[3]Interstate motor coach or charter buses.

As a result of the Normandy, Missouri, accident in which four pedestrians were killed and three injured, the Safety Board held a public hearing on March 3 and 4, 1998, to determine the extent of transit bus safety oversight. During the public hearing, witnesses representing State and Federal government agencies testified as well as representatives from several transit agencies, member service organizations, and State associations. The participants in the hearing discussed transit agency self-regulation, the extent of Federal and State safety oversight, accident data, pupil transportation, and driver selection and qualification.

After the Safety Board conducted several accident investigations involving transit buses and held the public hearing on transit bus safety in March 1998, it found that substantial safety deficiencies and little Federal or State government safety oversight exist within the transit bus industry. The Safety Board understands that the Federal Government is spending $6.34 billion to subsidize the operation of transit agencies;[4] yet, its safety oversight of transit bus operations is essentially nonexistent. The public expects that transit bus operations, whether publicly owned or subsidized, are safe.[5]

Although safety programs at the Federal level are essentially nonexistent and the State programs vary, the American Public Transit Association (APTA) has developed two programs to provide for safe operations at its member transit agencies. However, these programs are not available to all transit agencies (only to APTA membership, which is less than 10 percent of all transit agencies) and have a fee associated with them.

APTA has drafted the Bus Safety Management Program (BSMP), a system safety program that will be applicable to transit bus operations, as well as the *Manual for the Development of Bus Transit System Safety Program Plans*. The BSMP is similar to the APTA rail rapid transit system safety program, on which the FTA State Safety Oversight of Rail Fixed Guideway Systems Program was modeled. The BSMP will help transit agencies set up a safety program in conformance with the *Manual for the Development of Bus Transit System Safety Program Plans*. APTA will then examine each system safety program on a triennial basis and evaluate whether the transit agency has: a system safety program plan that is in conformance with the APTA *Manual for the Development of Bus Transit System Safety Program Plans*; its system safety program plan fully implemented; and conducted an internal safety audit program to identify, track, and resolve safety program deficiencies. However, compliance with the safety oversight of operations will still be the responsibility of the individual transit agency even with the implementation of the BSMP.

In 1993, APTA conducted a survey of the hiring practices of various transit agencies because of concerns within the transit industry about the ratio of accident and employee-retention rates of newly hired drivers compared with experienced drivers. Over 100 agencies responded to the survey, resulting in the APTA conclusion that the then-existing recruiting and hiring

---

[4]Of this amount, over $2.5 billion is provided for transit bus operations.

[5]For more detailed information, read Special Investigation Report—*Transit Bus Safety Oversight* (NTSB/SIR-98/03).

practices were extremely diverse. In December 1994, APTA published the final report *Bus Operator Selection System*[6] (BOSS), which details a selection system that could be adopted by a transit agency and allow the recruitment of drivers who would be more likely to maintain stable attendance and employment records. In addition to employment stability, according to APTA, this system would also reduce the accident rates typically experienced with new operators, as has been encountered by those transit agencies that evaluated the system.

Since its inception, BOSS has been implemented at 31 agencies, including the New York City Transit Authority, and numerous agencies are in the process of implementing this selection system. According to APTA testimony at the public hearing, program start-up requires a major commitment on the part of the transit agency to internally probe its processes and to involve its human resource and operations people in preparing for implementation. Additionally, the BOSS program has a cost factor associated with it for the ongoing support of the consultant who developed it. APTA believes that because of these factors, the BOSS program will probably require time to be universally accepted and applied but eventually all APTA transit agency members will use the program.

At the public hearing, the CTAA voiced its concern that the BOSS program primarily addresses the problems facing the APTA membership. The CTAA emphasized that New York City alone hires about 1,200 bus operators annually and the rural transit network nationwide totals only between 6,000 and 7,000 bus operators. The number difference in hiring demands results in different training and recruitment needs for smaller rural transit systems. The typical CTAA member employs a total of six busdrivers, whose employment involves low turnover and wages. The CTAA also testified that because its members operate in rural areas, the labor market is limited and many of the operators believe that they are almost forced to hire the available drivers and then attempt to train them to be qualified safe bus operators.

While APTA has taken steps to ensure that uniform safety and qualifications will be applied to its member transit bus agencies, this only represents 10 percent of all transit agencies. Consequently, the Safety Board concludes that a model comprehensive safety program is not available for all transit bus agencies, only urban transit agencies that are members of APTA.

Therefore, the National Transportation Safety Board recommends that the Community Transportation Association of America:

> Develop, in cooperation with the U.S. Department of Transportation, the American Public Transit Association, and the American Association of State Highway and Transportation Officials, a model comprehensive safety program(s). (H-98-48)

[6]APTA contracted Landy Jacobs, Inc., a human resource consulting firm based in State College, Pennsylvania, to develop this project.

In addition, the Safety Board issued Safety Recommendations H-98-43 through -46 to the U.S. Department of Transportation, H-98-47 to the American Public Transit Association, and H-98-49 to the American Association of State Highway and Transportation Officials.

The National Transportation Safety Board is an independent Federal agency with the statutory responsibility "to promote transportation safety by conducting independent accident investigations and by formulating safety improvement recommendations" (Public Law 93-633). The Safety Board is vitally interested in any action taken as a result of its safety recommendations. Therefore, it would appreciate a response from you regarding action taken or contemplated with respect to the recommendation in this letter. Please refer to Safety Recommendation H-98-48 in your reply. If you need additional information, you may call (202) 314-6441.

Chairman HALL, Vice Chairman FRANCIS, and Members HAMMERSCHMIDT, GOGLIA, and BLACK concurred in this recommendation.

Jim Hall

By: Jim Hall
Chairman

National Transportation Safety Board

Washington, D.C. 20594

Safety Recommendation

Date: November 30, 1998

In Reply Refer To: H-98-49

Mr. Francis B. Francois
Executive Director
American Association of State Highway and Transportation Officials
444 North Capitol Street, N.W.
Washington, D.C. 20001

Recently, the National Transportation Safety Board has investigated transit bus accidents in Normandy, Missouri; Cosmopolis, Washington; New York, New York; and Nashville, Tennessee.[1] The Normandy, New York, and Nashville accidents exposed various operational deficiencies such as unqualified drivers, drivers with hazardous medical conditions, inadequate maintenance practices, and the operation of buses with mechanical defects. The Cosmopolis accident revealed that certain laws and school transportation safety operational practices are not applicable to transit operations.[2] Had these deficiencies been found during other types of bus operations,[3] which fall under Federal and State government safety regulations, sanctions could have been imposed, such as assessing fines, taking the buses out of service, or suspending the company operations. However, no such Federal regulations are in place for transit buses. Of the four accident locations, only New York conducts some type of oversight of transit bus operations.

[1]For more detailed information, read Highway Accident Summary Report—*Transit Bus Collision with Pedestrians, Normandy, Missouri, June 11, 1997* (NTSB/HAR-98/01/SUM); Highway Accident/Incident Summary Report—*Collision with a Pedestrian by a Utility Truck near Cosmopolis, Washington, November 26, 1996* (NTSB/HAR-97/01/SUM); and National Transportation Safety Board Accident Investigations—*Transit Bus Collision with Pedestrian in New York City, New York, October 2, 1997* (HWY98FH019) and *Transit Bus Collision with Multiple Vehicles in Nashville, Tennessee, August 31, 1998* (HWY98FH042).

[2]Laws that require traffic to stop for school buses that are loading or discharging students are not in effect for transit buses. A transit bus is neither painted yellow, equipped with stop arms or bars, nor required to have its driver ensure that children are safely out of the roadway after exiting the bus.

[3]Interstate motor coach or charter buses.

As a result of the Normandy, Missouri, accident in which four pedestrians were killed and three injured, the Safety Board held a public hearing on March 3 and 4, 1998, to determine the extent of transit bus safety oversight. During the public hearing, witnesses representing State and Federal government agencies testified as well as representatives from several transit agencies, member service organizations, and State associations. The participants in the hearing discussed transit agency self-regulation, the extent of Federal and State safety oversight, accident data, pupil transportation, and driver selection and qualification.

After the Safety Board conducted several accident investigations involving transit buses and held the public hearing on transit bus safety in March 1998, it found that substantial safety deficiencies and little Federal or State government safety oversight exist within the transit bus industry. The Safety Board understands that the Federal Government is spending $6.34 billion to subsidize the operation of transit agencies;[4] yet, its safety oversight of transit bus operations is essentially nonexistent. The public expects that transit bus operations, whether publicly owned or subsidized, are safe.[5]

Although safety programs at the Federal level are essentially nonexistent and the State programs vary, the American Public Transit Association (APTA) has developed two programs to provide for safe operations at its member transit agencies. However, these programs are not available to all transit agencies (only to APTA membership, which is less than 10 percent of all transit agencies) and have a fee associated with them.

APTA has drafted the Bus Safety Management Program (BSMP), a system safety program that will be applicable to transit bus operations, as well as the *Manual for the Development of Bus Transit System Safety Program Plans*. The BSMP is similar to the APTA rail rapid transit system safety program, on which the FTA State Safety Oversight of Rail Fixed Guideway Systems Program was modeled. The BSMP will help transit agencies set up a safety program in conformance with the *Manual for the Development of Bus Transit System Safety Program Plans*. APTA will then examine each system safety program on a triennial basis and evaluate whether the transit agency has: a system safety program plan that is in conformance with the APTA *Manual for the Development of Bus Transit System Safety Program Plans*; its system safety program plan fully implemented; and conducted an internal safety audit program to identify, track, and resolve safety program deficiencies. However, compliance with the safety oversight of operations will still be the responsibility of the individual transit agency even with the implementation of the BSMP.

In 1993, APTA conducted a survey of the hiring practices of various transit agencies because of concerns within the transit industry about the ratio of accident and employee-retention rates of newly hired drivers compared with experienced drivers. Over 100 agencies responded to the survey, resulting in the APTA conclusion that the then-existing recruiting and hiring

---

[4]Of this amount, over $2.5 billion is provided for transit bus operations.

[5]For more detailed information, read Special Investigation Report—*Transit Bus Safety Oversight* (NTSB/SIR-98/03).

practices were extremely diverse. In December 1994, APTA published the final report *Bus Operator Selection System*[6] (BOSS), which details a selection system that could be adopted by a transit agency and allow the recruitment of drivers who would be more likely to maintain stable attendance and employment records. In addition to employment stability, according to APTA, this system would also reduce the accident rates typically experienced with new operators, as has been encountered by those transit agencies that evaluated the system.

Since its inception, BOSS has been implemented at 31 agencies, including the New York City Transit Authority, and numerous agencies are in the process of implementing this selection system. According to APTA testimony at the public hearing, program start-up requires a major commitment on the part of the transit agency to internally probe its processes and to involve its human resource and operations people in preparing for implementation. Additionally, the BOSS program has a cost factor associated with it for the ongoing support of the consultant who developed it. APTA believes that because of these factors, the BOSS program will probably require time to be universally accepted and applied but eventually all APTA transit agency members will use the program.

At the public hearing, the Community Transportation Association of America (CTAA) voiced its concern that the BOSS program primarily addresses the problems facing the APTA membership. The CTAA emphasized that New York City alone hires about 1,200 bus operators annually and the rural transit network nationwide totals only between 6,000 and 7,000 bus operators. The number difference in hiring demands results in different training and recruitment needs for smaller rural transit systems. The typical CTAA member employs a total of six busdrivers, whose employment involves low turnover and wages.[7] The CTAA also testified that because its members operate in rural areas, the labor market is limited and many of the operators believe that they are almost forced to hire the available drivers and then attempt to train them to be qualified safe bus operators.

While APTA has taken steps to ensure that uniform safety and qualifications will be applied to its member transit bus agencies, this only represents 10 percent of all transit agencies. Consequently, the Safety Board concludes that a model comprehensive safety program is not available for all transit bus agencies, only urban transit agencies that are members of APTA.

The National Transportation Safety Board, therefore, recommends that the American Association of State Highway and Transportation Officials:

> Develop, in cooperation with the U.S. Department of Transportation, the American Public Transit Association, and the Community Transportation Association of America, a model comprehensive safety program(s). (H-98-49)

---

[6]APTA contracted Landy Jacobs, Inc., a human resource consulting firm based in State College, Pennsylvania, to develop this project.

[7]Approximately 10 percent of the CTAA's membership only pay their busdrivers minimum wage.

In addition, the Safety Board issued Safety Recommendations H-98-43 through -46 to the U.S. Department of Transportation, H-98-47 to the American Public Transit Association, H-98-48 to the Community Transportation Association of America.

The National Transportation Safety Board is an independent Federal agency with the statutory responsibility "to promote transportation safety by conducting independent accident investigations and by formulating safety improvement recommendations" (Public Law 93-633). The Safety Board is vitally interested in any action taken as a result of its safety recommendations. Therefore, it would appreciate a response from you regarding action taken or contemplated with respect to the recommendation in this letter. Please refer to Safety Recommendation H-98-49 in your reply. If you need additional information, you may call (202) 314-6441.

Chairman HALL, Vice Chairman FRANCIS, and Members HAMMERSCHMIDT, GOGLIA, and BLACK concurred in this recommendation.

Jim Hall

By: Jim Hall
Chairman

National Transportation Safety Board

Washington, D.C. 20594

Safety Recommendation

Date: November 18, 1998

In reply refer to: P-98-30

Ms. Kelley Coyner
Administrator
Research and Special Programs Administration
400 7th Street, S.W.
Washington, D.C. 20590

About 11:54 p.m. eastern daylight time on June 26, 1996, a 36-inch-diameter Colonial Pipeline Company pipeline ruptured where a corroded section of the pipeline crossed the Reedy River at Fork Shoals, South Carolina. The ruptured pipeline released about 957,600 gallons of fuel oil into the Reedy River and surrounding areas. The estimated cost to Colonial for cleanup and settlement with the State of South Carolina was $20.5 million. No one was injured in the accident.[1]

The National Transportation Safety Board determined that the probable cause of the rupture of the corrosion-weakened pipeline at the Reedy River crossing was the failure of Colonial Pipeline Company (1) to have adequate management controls in place to protect the corroded pipeline at the Reedy River crossing; and (2) to ensure that pipeline controllers were adequately trained to both recognize and respond properly to operational emergencies, abnormal conditions, and pipeline leaks.

On the evening of June 26, 1996, a Colonial Pipeline Company relief pipeline controller was on duty at Colonial's pipeline control center in Atlanta, Georgia, operating a 36-inch-diameter Colonial pipeline (designated line No. 2) between Pasadena, Texas, and Greensboro, North Carolina. The relief controller was making and monitoring deliveries of No. 2 fuel oil from the pipeline to terminals in Atlanta, Charlotte, and Greensboro.

At 11:45:30 p.m., the deliveries to Atlanta were terminated, and the controller began sequentially increasing pumping capacity[2] at the unattended pumping stations downstream of Atlanta to accommodate the additional product that was now moving through the pipeline. At

[1] For more information, read Pipeline Accident Report--*Pipeline Rupture and Release of Fuel Oil into the Reedy River at Fork Shoals, South Carolina, June 26, 1996* (NTSB/PAR-98/01).

[2] Pumping capacity could be increased either by starting an additional pump at a station or by turning on a larger (higher hp rating) pump and turning off a smaller one.

11:50:13 p.m., the controller started a second pumping unit at the Simpsonville, South Carolina, station, bringing that station's pumping power to 7,000 hp.

About 1 minute later, the pipeline controller attempted to remotely start the 5,000-hp No. 3 pumping unit at the Gastonia, North Carolina, station. Unknown to the controller, the pump did not start. Believing that he now had two pump units on line at Gastonia, and without waiting for the supervisory control and data acquisition (SCADA) system pressure readings to confirm the starting of the No. 3 pump, the controller shut down the 2,000-hp pumping unit that had been running at Gastonia. Shutting down this unit left no pumps on line at Gastonia, with the result that, 11 seconds after the shutdown, the automatic mainline block valve began opening to allow product to bypass the pump units at the Gastonia station. This triggered a SCADA alarm, which the controller acknowledged. The controller took no further action regarding Gastonia at that time. Instead, he changed the SCADA monitor screen (which he was using to control pump starts and shutdowns) to display the next downstream station at Kannapolis, North Carolina, where he sent a command to start a 5,000-hp pumping unit.

The controller said he noticed the "pressure spread" on the SCADA console and realized that the Gastonia No. 3 pumping unit was not on line. The controller said that he felt he had "to get something on [at Gastonia]," so he started the 5,000-hp No. 4 pumping unit there.

Meanwhile, the controller's shutting down of the only operating pump at Gastonia had generated a pressure surge in the pipeline. The surge traveled upstream and caused the 5,000-hp No. 4 pumping unit (the only unit running) at Gaffney to shut down because of high discharge pressure. According to SCADA system records, the controller tried to restart the No. 4 pump at Gaffney. When that pump would not start, he started the 5,000-hp No. 3 pump instead.

At 11:53:58 p.m., the 2,000-hp No. 1 pumping unit at Simpsonville shut down on high discharge pressure, followed 3 seconds later by the shutdown of the 5,000-hp No. 3 unit. The controller said he noticed both of the pump units at Simpsonville suddenly go down and noticed the pressure increase there. He started the 5,000-hp No. 2 pumping unit at Simpsonville, but this unit ran for only 19 seconds before it too shut down. The shutdown of these pumps increased pressure in the pipeline upstream of the Simpsonville station. At 11:54:28 p.m., the Simpsonville suction pressure dropped to -8 psig. Line No. 2 had ruptured at the Reedy River, about 5 miles upstream of Simpsonville.

When deliveries to the Atlanta terminal were closed out, the controller had to perform a series of operations in a certain sequence and within a fairly brief period of time to prevent an over-pressure condition from occurring somewhere downstream of Atlanta. Because of the weakened pipe at Reedy River and the pressures that were being run in the system, any error in operating the pipeline could have serious consequences. Such an error was the inadvertent shutdown of the Gastonia station.

When the controller became aware that the Gastonia station was down, he immediately attempted to start a pump there. The action specified in Colonial's operations manual for such an event would have been to immediately begin shutting down the line using the multiple station shutdown procedures. This action may or may not have prevented the accident; however, at the very least, shutting down the pipeline at that time would have reduced the amount of product that was eventually released, thereby reducing the amount of environmental damage.

Even after the Gastonia and Simpsonville stations shut down automatically because of high discharge pressure, the controller did not initiate a shutdown of the pipeline. A pipeline shutdown was not initiated until after the relief controller had notified the shift supervisor of problems on the line and the two men discussed the situation, which was about 3 1/2 minutes after the rupture. The Safety Board concluded that the controller's failure to independently effect an earlier shutdown of the pipeline contributed to the amount of product lost from the ruptured pipe.

The controller's work shifts for the day before and the day of the accident represent an "inverted schedule" that may cause circadian rhythm desynchronization. His work shift on the day of the accident was 12 hours out of phase with the shift he had worked the day before and with the sleep/wake cycle he had been accustomed to for the previous 5 days. The day before the accident, the controller's work day ended at 7 p.m. On the day of the accident, the shift began at that time and was scheduled to end at 7 a.m. the following day. Such a dramatic change of work shift is likely to cause fatigue. Fatigue may also have been exacerbated by the controller's having been awake for almost 17 hours at the time the accident occurred.[3] In any case, the controller could have been suffering from fatigue despite the 8 to 9 hours of sleep he said he got the night before. As noted previously, during the 5 nights prior to the accident, the controller had been asleep at the time of day that the accident occurred. The Safety Board therefore concluded that fatigue resulting from the relief controller's inverted work schedule may have affected his alertness, vigilance, and responsiveness during the accident sequence.

The Safety Board is also concerned about the potential for fatigue with the rotating schedules for pipeline controllers. In an operating environment that demands prolonged periods of continuous vigilance, the potential impact of fatigue on controllers must be carefully assessed. Circadian clocks can be reset to accommodate work shift changes, but the necessary physiological adjustment does not occur quickly. The adaptation may take from days to weeks; some research indicates an adaptation rate of about 1 hour per day.[4]

Studies have shown that shift workers who rotate schedules that include night shifts are especially prone to fatigue on both the first and second nights of the work week. This slow adaptation process highlights the importance of addressing circadian rhythms in scheduling for 24-hour operations. An employer's schedule for changing shifts must incorporate sufficient time for the employee to adapt the circadian rhythms.

In the view of the Safety Board, a comprehensive assessment incorporating the extensive body of scientific knowledge that exists concerning fatigue, sleep, and circadian physiology as they relate to work/rest schedules has not been made regarding the potential safety risks posed by rotating shifts for pipeline controllers. Therefore, the National Transportation Safety Board makes the following safety recommendation to the Research and Special Programs Administration:

---

[3] Determining the relief controller's prior wakefulness was problematic because he could not recall whether he had napped before going to work on June 26.

[4] Wever, R., "Phase Shifts of Human Circadian Rhythms Due to Shifts of Artificial Zeitgebars," *Chronobiologia 7*, 1980, pp. 303-327.

Assess the potential safety risks associated with rotating pipeline controller shifts and establish industry guidelines for the development and implementation of pipeline controller work schedules that reduce the likelihood of accidents attributable to controller fatigue. (P-98-30)

Also, the Safety Board issued Safety Recommendations P-98-31 through -33 to Colonial Pipeline Company.

Please refer to Safety Recommendation P-98-30 in your reply.

Chairman HALL, Vice Chairman FRANCIS, and Members HAMMERSCHMIDT, GOGLIA, and BLACK concurred in this recommendation.

By: Jim Hall
Chairman

National Transportation Safety Board

Washington, D.C. 20594

Safety Recommendation

Date: November 18, 1998

In reply refer to: P-98-31 through -33

Mr. David Lemmon
President and Chief Executive Officer
Colonial Pipeline Company
945 East Paces Ferry Road
Atlanta, Georgia 30326

About 11:54 p.m. eastern daylight time on June 26, 1996, a 36-inch-diameter Colonial Pipeline Company pipeline ruptured where a corroded section of the pipeline crossed the Reedy River at Fork Shoals, South Carolina. The ruptured pipeline released about 957,600 gallons of fuel oil into the Reedy River and surrounding areas. The estimated cost to Colonial for cleanup and settlement with the State of South Carolina was $20.5 million. No one was injured in the accident.[1]

The National Transportation Safety Board determined that the probable cause of the rupture of the corrosion-weakened pipeline at the Reedy River crossing was the failure of Colonial Pipeline Company (1) to have adequate management controls in place to protect the corroded pipeline at the Reedy River crossing; and (2) to ensure that pipeline controllers were adequately trained to both recognize and respond properly to operational emergencies, abnormal conditions, and pipeline leaks.

Colonial, once it became aware of the corrosion damage at the Reedy River crossing, immediately made plans to replace the defective pipe. Until the pipe could be replaced, the company placed operating restrictions (consisting of altered pressure valve and switch settings and a 100-psig suction pressure/5,000-hp limit at Simpsonville) on line No. 2 that were intended to protect the corrosion-weakened section of pipe by limiting the maximum pressure to which it might be subjected during an abnormal condition. The restrictions were approved by the vice president of operations and transmitted through official company channels to all affected employees. The Safety Board investigation determined that all controllers and shift supervisors responsible for operating line No. 2 were aware of the restrictions.

Less than 1 month after the restrictions were put in place, the operations team leader authorized raising the 5,000-hp limit at Simpsonville to 7,000. The Safety Board is concerned about

[1] For more information, read Pipeline Accident Report--*Pipeline Rupture and Release of Fuel Oil into the Reedy River at Fork Shoals, South Carolina, June 26, 1996* (NTSB/PAR-98/01).

6758A

this change and the manner in which it was made. The recommendations of the hydraulics engineer had specified both a suction pressure limit and a horsepower limit at Simpsonville. If horsepower were to be increased beyond the specified 5,000, other changes may have been necessary to keep the combined pressure and throughput at a level that, in a worst-case scenario, would not result in a pipe failure at Reedy River. No such reevaluation was made, however. Nor was evidence found to indicate that those involved in this decision to run 7,000 hp had brought the issue to the attention of higher-level management so that ways other than increasing operating horsepower might be found to maintain safe operating conditions at Simpsonville.

The original restrictions had been approved by the vice president of operations, but that individual was not involved in the decision to alter them. Instead, the operations team leader removed the horsepower restriction without the knowledge of the vice president of operations and without benefit of a thorough analysis of the change or its implications for safe operation of the pipeline. The Safety Board concluded that technical input was not sought and the appropriate levels of management were not involved in the decision to disregard the 5,000-hp limit at the Simpsonville pumping station, with the result that safeguards designed to protect the corroded section of pipeline were bypassed.

For almost 2 months before the accident, Colonial operations management allowed line No. 2 to be operated without the 5,000-hp restriction at Simpsonville. Further, in the 2 weeks preceding the accident, suction pressure at Simpsonville was allowed to exceed 100 psig about 10 percent of the time. Absent an abnormal shutdown of the Simpsonville station or another station downstream of the Reedy River crossing, the pipeline could be operated without incident. During the period when the restrictions for Simpsonville were not being observed, however, any shutdown of the Simpsonville station during abnormal conditions could have precipitated the failure of the pipe at the Reedy River.

Colonial management, after issuing directives to address the potential hazard at the river crossing, did not effectively monitor pipeline operations to determine if the directives were practicable or were being observed. A maximum suction pressure alarm for the Simpsonville station was not installed to alert controllers or supervisors when the suction pressure restriction was exceeded;[2] shift supervisors were not directed to specifically monitor the operation of line No. 2 to help ensure compliance; and controllers were not directed to immediately report to supervisors any difficulties they noted in adhering to the restrictions.

The Safety Board therefore concluded that Colonial management failed to take the necessary measures to ensure that its line No. 2 was operated in a manner consistent with the restrictions placed on the line to prevent a failure in the corrosion-damaged pipe segment across the Reedy River. The ease with which operating restrictions on the Simpsonville station were removed indicates that a more methodical decisionmaking process that is firmly based on an analysis of operating parameters should be institutionalized within Colonial.

The relief controller's work shifts for the day before and the day of the accident represent an "inverted schedule" that may cause circadian rhythm desynchronization. His work shift on the day of the accident was 12 hours out of phase with the shift he had worked the day before and with the sleep/wake cycle he had been accustomed to for the previous 5 days. The day before the

[2] Such an alarm was installed after the accident.

accident, the relief controller's work day ended at 7 p.m. On the day of the accident, the shift began at that time and was scheduled to end at 7 a.m. the following day. Such a dramatic change of work shift is likely to cause fatigue. Fatigue may also have been exacerbated by the relief controller's having been awake for almost 17 hours at the time the accident occurred.[3] In any case, the relief controller could have been suffering from fatigue despite the 8 to 9 hours of sleep he said he got the night before. As noted previously, during the 5 nights prior to the accident, the relief controller had been asleep at the time of day that the accident occurred. The Safety Board therefore concluded that fatigue resulting from the relief controller's inverted work schedule may have affected his alertness, vigilance, and responsiveness during the accident sequence.

The Safety Board is also concerned about the potential for fatigue with the rotating schedules for pipeline controllers. In an operating environment that demands prolonged periods of continuous vigilance, the potential impact of fatigue on controllers must be carefully assessed. Circadian clocks can be reset to accommodate work shift changes, but the necessary physiological adjustment does not occur quickly. The adaptation may take from days to weeks; some research indicates an adaptation rate of about 1 hour per day.[4]

Studies have shown that shift workers who rotate schedules that include night shifts are especially prone to fatigue on both the first and second nights of the work week. This slow adaptation process highlights the importance of addressing circadian rhythms in scheduling for 24-hour operations. An employer's schedule for changing shifts must incorporate sufficient time for the employee to adapt the circadian rhythms. In the view of the Safety Board, Colonial has not adequately considered the potential for fatigue to adversely impact safety. An example is the company's job description that states that the operations team leader must be able to work "extended periods of time (18-36 hrs) continuously while being able to think and write clearly." Such a requirement is not scientifically valid.

The relief controller was the only employee toxicologically tested after this accident. At the direction of the operations team leader, through the shift supervisor, the relief controller was tested for drugs, but not for alcohol. The operations team leader said that breath or blood samples (for alcohol testing) were not obtained because he believed that such testing would be part of the regular drug test and thus did not specifically request it. The drug and alcohol test checklist provided by Colonial clearly indicated that drug testing and alcohol testing were considered by the company to be separate tests. The form also indicated that both tests were to be performed after a pipeline accident.

The investigation of this accident found no evidence that the relief controller may have been impaired by alcohol on the night of the accident, and the controller told investigators that he had not consumed any alcohol before reporting to work. Nonetheless, because Colonial officials did not follow established company procedures and conduct postaccident alcohol testing, neither the Safety Board nor Colonial could empirically determine that alcohol did not play a role in the

[3] Determining the relief controller's prior wakefulness was problematic because he could not recall whether he had napped before going to work on June 26.

[4] Wever, R., "Phase Shifts of Human Circadian Rhythms Due to Shifts of Artificial Zeitgebars," *Chronobiologia 7*, 1980, pp. 303-327.

accident or in the response to it. The Safety Board concluded that the failure of Colonial to perform postaccident alcohol tests indicates that the company did not effectively communicate to all its operating personnel and managers that postaccident tests must include testing for drugs and alcohol and that both tests must be specified.

The Safety Board therefore makes the following safety recommendations to Colonial Pipeline Company:

> Develop and implement management procedures requiring that proper engineering or hydraulic evaluation and analysis be performed before changes are made to line operating parameters that have been set by company management. (P-98-31)

> Assess the potential safety risks associated with your controller and relief controller rest/work schedules and modify, as necessary, those schedules to ensure that controller performance is not compromised by fatigue. (P-98-32)

> Review your drug and alcohol testing program and ensure that all operating employees and managers are familiar with the program and program requirements, to include the distinction between tests for alcohol and tests for other drugs. (P-98-33)

Also, the Safety Board issued Safety Recommendation P-98-30 to the Research and Special Programs Administration.

The National Transportation Safety Board is an independent Federal agency with the statutory responsibility "to promote transportation safety by conducting independent accident investigations and by formulating safety improvement recommendations" (Public Law 93-633). The Safety Board is vitally interested in any action taken as a result of its safety recommendations. Therefore, it would appreciate a response from you regarding action taken or contemplated with respect to the recommendations in this letter. Please refer to Safety Recommendations P-98-31 through -33 in your reply.

Chairman HALL, Vice Chairman FRANCIS, and Members HAMMERSCHMIDT, GOGLIA, and BLACK concurred in these recommendations.

By: Jim Hall
Chairman

National Transportation Safety Board

Washington, D.C. 20594

Safety Recommendation

Date: November 18, 1998

In reply refer to: P-98-34 through -38

Ms. Kelley S. Coyner
Administrator
Research and Special Programs Administration
400 Seventh Street, S.W.
Washington, D.C. 20590

On Saturday, August 24, 1996, about 3:26 p.m., an 8-inch-diameter steel LPG (liquefied petroleum gas) pipeline transporting liquid butane, operated by Koch Pipeline Company, LP (Koch), ruptured near Lively, Texas, sending a butane vapor cloud into a surrounding residential area.[1] The butane vapor ignited as two area residents in a pickup truck drove into the vapor cloud. The two people died at the accident site from thermal injuries. About 25 families were evacuated from the affected area. Koch estimated its direct pipeline losses, including the loss of product from the line, to be about $217,000. Other property losses included damage to the roadway under which the rupture occurred and damage to a pickup truck, a mobile home, several outbuildings, and adjacent woodlands.

The National Transportation Safety Board determined that the probable cause of this accident was the failure of Koch to adequately protect its pipeline from corrosion.

A catastrophic corrosion failure occurred in an area of the pipeline where significantly less corrosion had been identified by an internal inspection tool about 15 months earlier. When buried pipe was exposed in 1995 after this internal inspection, Koch recorded low pipe-to-soil potentials, many of which were below the company standard for cathodic protection. In addition, stress cracking and disbonded coating were observed at numerous locations and recorded in the field reports. Because cathodic protection levels were inadequate, the stress cracks that existed in the coating created areas in which rapid corrosion could occur. In addition, disbonded tape coating most likely created locally shielded areas on the pipe that prevented adequate cathodic protection current from reaching its surface, creating other areas in which rapid corrosion could occur. Despite these indications, Koch did not ensure that cathodic protection levels were restored to the company standard. The Safety Board concluded that although Koch's records

[1] For more detailed information, read Pipeline Accident Summary Report—*Pipeline Rupture, Liquid Butane Release, and Fire, Lively, Texas, August 24, 1996* (NTSB/PAR-98/02/SUM).

contained information that cathodic protection levels were inadequate and that active corrosion was occurring on its pipeline system before the accident, the conditions went uncorrected. In addition, excavations made as a result of the accident and during the 1996 internal inspection performed after the accident indicated that active corrosion was continuing on the pipeline.

Following the accident, the Office of Pipeline Safety (OPS) issued a hazardous facility order (HFO) directing Koch to prepare a written plan for a program of tests and studies to identify the extent of the external corrosion problem and proposals for correcting the problem. Koch took a number of actions to improve corrosion protection on its pipeline. The company also indicated that it was evaluating alternatives for ensuring the integrity of the pipeline section between the Nevada and the Corsicana pump stations, which represents about 70 miles of its 570-mile pipeline system. Koch's field reports, however, indicate that the corrosion problem extends beyond the 70-mile section proposed for repair or replacement. In addition, the HFO does not contain a specific requirement to evaluate coating condition. The Safety Board concluded that the tape coating on Koch's entire 8-inch pipeline may have stress cracking and disbondment.

Koch informed the Safety Board that as of September 1998, the company was expanding the distribution of its field reports and notifying corrosion technicians when specific conditions were detected so that a field inspection could be made. The Safety Board believes, however, that Koch needs to take more comprehensive action to evaluate data so that it can promptly provide adequate corrosion protection to its pipeline.

In the course of its investigation of the Lively accident, the Safety Board determined that Federal regulations do not contain requirements for determining and subsequently evaluating the coating condition on pipelines. The Board concluded that because no overall requirement exists for operators to evaluate pipeline coating condition, problems similar to those that occurred on Koch's pipeline could occur on other pipelines.

The lack of performance measures for adequate cathodic protection on liquid pipelines has been an ongoing problem. The OPS merely requires that pipeline operators conduct tests annually (not to exceed 15 months between tests) for pipelines under cathodic protection to determine that the protection is adequate (49 CFR 195.416). The regulation does not provide performance measures for "adequate cathodic protection" for liquid pipelines. However, performance measures for cathodic protection can be found in appendix D of the gas pipeline safety regulations, 49 CFR 192. The Safety Board, as a result of its investigation of a 1986 accident[2] involving a liquid pipeline, recommended that RSPA provide cathodic protection criteria for liquid pipelines:

[2] For more detailed information, read Pipeline Accident Report—*Williams Pipe Line Company Liquid Pipeline Rupture and Fire, Mounds View, Minnesota, July 8, 1986* (NTSB/PAR-87/02).

P-87-24

Revise 49 CFR Part 195 to include criteria, similar to those found in Part 192, against which liquid pipeline operators can evaluate their cathodic protection systems.

Because RSPA failed to take meaningful action to address this recommendation, the Safety Board classified Safety Recommendation P-87-24 "Closed—Unacceptable Action" on January 23, 1996. However, the Safety Board finds that the Lively accident illustrates the continuing need for performance measures for adequate cathodic protection on liquid pipelines.

Another area that the Safety Board examined in its investigation of this accident was the effectiveness of Koch's public education program, to include distribution, content, and program evaluation. In 1991 and 1992, public education materials were hand-distributed door to door by company representatives. In 1992, Koch produced a report that included tabulations of the total number of material packets issued and the response cards returned to the company. From 1993 through early 1996, Koch distributed its public education materials by annual mailings, using addresses compiled from returned response cards, from lists developed by company representatives canvassing the area, and from property right-of-way records.

Before the accident, Koch developed its mailing list through door-to-door canvassing and then used response card returns to verify the accuracy of coverage in the accident area. However, during the 1996 mailing, only 5 of the 45 residences near the accident site were sent Koch's educational materials. Significantly, Koch's 1996 mailing list did not include the two families that suffered fatalities in the accident. In all, Koch's mailing on the dangers of a pipeline release and actions to take during a pipeline emergency reached only a limited number of people living near the accident location. The Safety Board therefore concluded that Koch's distribution program for its public education materials before the accident was inadequate.

The content of the 1996 bulletin sent by Koch as part of its public education package before the accident had two important shortcomings. The bulletin's first shortcoming was that key information on recognizing a leak and taking appropriate action lacked clarity and was not formatted to alert readers to its importance. In addition, the complex language used in the bulletin diluted the warning. The bulletin's second shortcoming was that the warning was not specific enough. It omitted crucial information such as warning people not to operate switches, equipment, machinery, or motor vehicles in or near a vapor cloud; not to light a match or smoke; and not to drive into or go back into the vapor cloud. Furthermore, the bulletin failed to urge readers to inform others in the household of the warning, which is a way to disseminate crucial safety information beyond the initial reader. Because of these shortcomings, the Safety Board concluded that the format and content of the public education bulletin mailed by Koch before the accident did not effectively convey important safety information to the public.

Examination of existing pipeline safety regulations indicates that they do not provide clear and specific requirements for the content and distribution of a pipeline operator's public education program. Further, existing safety regulations do not require pipeline companies to evaluate the effectiveness of their public education programs. Without such evaluations, operators may not realize that a program is not achieving its objectives. Based on its investigation, the Safety Board concluded that requirements for periodic evaluation of public education programs can help pipeline operators ensure that their programs are effective.

The National Transportation Safety Board therefore recommends that the Research and Special Programs Administration:

> Require that Koch Pipeline Company, LP, evaluate the integrity of the remainder of its HVL (highly volatile liquid) pipeline, including the condition of the coating, and rehabilitate the pipeline as necessary. (P-98-34)
>
> Revise 49 *Code of Federal Regulations* Part 195 to require pipeline operators to determine the condition of pipeline coating whenever pipe is exposed and, if degradation is found, to evaluate the coating condition of the pipeline. (P-98-35)
>
> Revise 49 *Code of Federal Regulations* Part 195 to include performance measures for the adequate cathodic protection of liquid pipelines. (P-98-36)
>
> Revise 49 *Code of Federal Regulations* Part 195 to include requirements for the content and distribution of liquid pipeline operators' public education programs. (P-98-37)
>
> Revise 49 *Code of Federal Regulations* Part 195 to require that pipeline operators periodically evaluate the effectiveness of their public education programs using scientific techniques. (P-98-38)

Also, the Safety Board issued Safety Recommendations P-98-39 to Koch Pipeline Company, LP, and P-98-40 to NACE International. Please refer to Safety Recommendations P-98-34 through -38 in your reply.

Chairman HALL, Vice Chairman FRANCIS, and Members HAMMERSCHMIDT, GOGLIA, and BLACK concurred in these recommendations.

By: Jim Hall
Chairman

National Transportation Safety Board

Washington, D.C. 20594

Safety Recommendation

Date: November 18, 1998

In reply to refer to: P-98-39

Mr. Anthony L. Botterwerk
President
Koch Pipeline Company, LP
411 E. 37th Street, North
Wichita, Kansas 67220

On Saturday, August 24, 1996, about 3:26 p.m., an 8-inch-diameter steel LPG (liquefied petroleum gas) pipeline transporting liquid butane, operated by Koch Pipeline Company, LP (Koch), ruptured near Lively, Texas, sending a butane vapor cloud into a surrounding residential area.[1] The butane vapor ignited as two area residents in a pickup truck drove into the vapor cloud. The two people died at the accident site from thermal injuries. About 25 families were evacuated from the affected area. Koch estimated its direct pipeline losses, including the loss of product from the line, to be about $217,000. Other property losses included damage to the roadway under which the rupture occurred and damage to a pickup truck, a mobile home, several outbuildings, and adjacent woodlands.

The National Transportation Safety Board determined that the probable cause of this accident was the failure of Koch to adequately protect its pipeline from corrosion.

A catastrophic corrosion failure occurred in an area of the pipeline where significantly less corrosion had been identified by an internal inspection tool about 15 months earlier. When buried pipe was exposed in 1995 after this internal inspection, Koch recorded low pipe-to-soil potentials, many of which were below the company standard for cathodic protection. In addition, stress cracking and disbonded coating were observed at numerous locations and recorded in the exposure reports. Despite these indications, Koch did not ensure that cathodic protection levels were restored to the company standard.

Excavations made as a result of the accident and during the 1996 internal inspection performed after the accident indicated that active corrosion was continuing on the pipeline. The Safety Board therefore concluded that although Koch's records contained information that

[1] For additional information, read Pipeline Accident Summary Report—*Pipeline Rupture, Liquid Butane Release, and Fire, Lively, Texas, August 24, 1996* (NTSB/PAR-98/02/SUM).

cathodic protection levels were inadequate and that active corrosion was occurring on its pipeline system before the accident, the conditions went uncorrected.

Koch informed the Safety Board that as of September 1998, the company was expanding the distribution of its field reports and notifying corrosion technicians when specific conditions are detected so that a field inspection can be made. The Safety Board believes, however, that Koch needs to take more comprehensive action to evaluate data so that it can promptly provide adequate corrosion protection to its pipeline.

Therefore, the National Transportation Safety Board recommends that Koch Pipeline Company, LP:

> Establish a procedure to promptly evaluate all data related to pipeline corrosion, such as annual cathodic protection surveys, field reports, internal inspection results, and coating condition data, to determine whether the pipeline's corrosion protection is adequate, and take necessary corrective action. (P-98-39)

Also, the Safety Board issued Safety Recommendations P-98-35 through -38 to the Research and Special Programs Administration and P-98-40 to NACE International.

The National Transportation Safety Board is an independent Federal agency with the statutory responsibility "to promote transportation safety by conducting independent accident investigations and by formulating safety improvement recommendations" (Public Law 93-633). The Safety Board is vitally interested in any action taken as a result of its safety recommendations. Therefore, it would appreciate a response from you regarding action taken or contemplated with respect to the recommendation in this letter. Please refer to Safety Recommendation P-98-39 in your reply.

Chairman HALL, Vice Chairman FRANCIS, and Members HAMMERSCHMIDT, GOGLIA, and BLACK concurred in this recommendation.

By: Jim Hall
Chairman

National Transportation Safety Board

Washington, D.C. 20594

Safety Recommendation

Date: November 18, 1998

In reply refer to: P-98-40

Mr. Gerald Shankel
Executive Director
NACE International
1440 South Creek Drive
Houston, Texas 77084-4906

On Saturday, August 24, 1996, about 3:26 p.m., an 8-inch-diameter steel LPG (liquefied petroleum gas) pipeline transporting liquid butane, operated by Koch Pipeline Company, LP (Koch), ruptured near Lively, Texas, sending a butane vapor cloud into a surrounding residential area.[1] The butane vapor ignited as two area residents in a pickup truck drove into the vapor cloud. The two people died at the accident site from thermal injuries. About 25 families were evacuated from the affected area. Koch estimated its direct pipeline losses, including the loss of product from the line, to be about $217,000. Other property losses included damage to the roadway under which the rupture occurred and damage to a pickup truck, a mobile home, several outbuildings, and adjacent woodlands.

The National Transportation Safety Board determined that the probable cause of this accident was the failure of Koch to adequately protect its pipeline from corrosion.

Following the accident, Koch contracted with a consultant to perform testing and analysis for bacteria on the pipe's surface. Koch's consultant used a procedure similar to NACE International Standard TM 0194-94, *Field monitoring of bacterial growth in oil field systems,* which describes field testing methods for estimating bacteria populations commonly found in oil field systems. This standard, however, is not directly applicable to sampling and testing for microbes on a pipeline's external surface. The consultant's analysis may have been inaccurate for several reasons, namely the pipe was cleaned before samples were collected, laboratory tests were performed about 2 days after the pipe was removed from the ground, and tap water was used in the tests. The Safety Board determined that the contribution of microbes to the corrosion damage could not be accurately determined because of inadequate sampling and testing techniques.

---

[1] For additional information, read Pipeline Accident Summary Report—*Pipeline Rupture, Liquid Butane Release, and Fire, Lively, Texas, August 24, 1996* (NTSB/PAR-98/02/SUM).

The National Transportation Safety Board therefore recommends that NACE International:

Develop a standard for microbial sampling and testing of external surfaces on an underground pipeline. (P-98-40)

Also, the Safety Board issued Safety Recommendations P-98-34 through -38 to the Research and Special Programs Administration and P-98-39 to Koch Pipeline Company, LP.

The National Transportation Safety Board is an independent Federal agency with the statutory responsibility "to promote transportation safety by conducting independent accident investigations and by formulating safety improvement recommendations" (Public Law 93-633). The Safety Board is vitally interested in any action taken as a result of its safety recommendations. Therefore, it would appreciate a response from you regarding action taken or contemplated with respect to the recommendation in this letter. Please refer to Safety Recommendation P-98-40 in your reply.

Chairman HALL, Vice Chairman FRANCIS, and Members HAMMERSCHMIDT, GOGLIA, and BLACK concurred in this recommendation.

Jim Hall

By: Jim Hall
Chairman

National Transportation Safety Board

Washington, D.C. 20594

Safety Recommendation

Date: November 24, 1998

In reply to refer to: R-98-67 and -68

Honorable Jolene M. Molitoris
Administrator
Federal Railroad Administration
400 Seventh Street, S.W.
Washington, D.C. 20590

At 4:30 a.m., on April 2, 1997, tank car ACAX 80010 arrived at the Illinois Central Railroad yard in Memphis, Tennessee, on Illinois Central train No. GEME 01. At 12:05 p.m., a railroad inspector noticed leakage from the tank car during switching operations. The tank car was filled with anhydrous hydrogen fluoride, a corrosive and poisonous liquid.[1] Vapor appeared to be leaking from a weld at a 2- by 3-foot patch in the tank wall. About 150 people (26 residences) were evacuated from a ½-mile radius around the yard for about 17 hours while the leak was controlled and the material was transferred to another tank car. No injuries were reported.

The National Transportation Safety Board determined that the probable cause of the failure of tank car ACAX 80010 was inadequate heat treatment to reduce the hardness of the weld material used in the repair of the tank to a level that would retard or prevent hydrogen-assisted cracking and inadequate testing to determine whether the weld material hardness exceeded established limits.

Tank car ACAX 80010 had been loaded at Allied-Signal, Inc., (the tank car owner and shipper) in Geismar, Louisiana, on March 17, 1997, and it was shipped on March 31, 1997, destined for Cameco in Port Hope, Ontario, Canada. This was the first shipment of product in this tank car since two hydrogen blisters[2] had been cut from the tank shell; one of the blisters was

[1] Anhydrous hydrogen fluoride is a colorless liquid that fumes in air and has a sharp, pungent odor. The U.S. Department of Transportation (DOT) defines the material as a Class 8 (corrosive) with a poison-inhalation hazard and assigns it to Packing Group I, which contains materials that represent the greatest hazard in transportation within that class and therefore require the strongest packaging.

[2] A hydrogen blister in steel is a bulge caused by molecular hydrogen trapped at an internal flaw within the steel.

on the bottom near the middle of the tank where the 2- by 3-foot patch had been welded into the tank.

The repairs were performed by Texana Tank Car & Manufacturing, Inc., (Texana) of Nash, Texas, on February 24, 1997. The two blisters and the adjacent steel were cut out, and 1-inch-thick American Society for Testing and Materials (ASTM) A516, grade 70 steel patches were butt-welded in the openings. After the repair, Texana stress-relieved the welds and the heat-affected zones in the material on each side of the welds at temperatures above 1100° F (about 1150° F) for about 1 hour. The weld material on each patch was then tested for hardness at only two locations; one on the interior and one on the exterior of the tank. The recorded hardness readings for the patch near the middle of the tank, where the leak occurred, were Rockwell C 15 (exterior) and C 17 (interior).[3] Before tank car ACAX 80010 was returned to service, the welds were radiographed and no defects were observed. The tank car was also twice hydrostatically tested to the required test pressure of 400 psig without evidence of leakage before it was filled with anhydrous hydrogen fluoride.

Postaccident examination of the tank car revealed a vertical through-wall crack in the upper horizontal leg of one of the butt welds made during the February 1997 repair. The examination revealed that the fracture surface had a "river pattern," indicating that the fracture initiated from multiple locations along the weld crown on the interior surface of the tank car (adjacent to the anhydrous hydrogen fluoride). The crack propagated through the entire weld fusion zone, except for one exterior weld bead. The crack also propagated through portions of the heat-affected zones on both sides of the weld. In these zones, areas of flat circular fractures were centered around cavities containing inclusions in the steel. Postaccident testing revealed that the hardness of the weld material near the crack site ranged from Rockwell C 26 to C 32 and averaged Rockwell C 29.

E.I. DuPont de Nemours (DuPont) has studied the effect of anhydrous hydrogen fluoride on carbon steel vessels. One DuPont study[4] documented three types of damage caused by atomic hydrogen involved in corrosion: hydrogen-assisted stress corrosion cracking, stress-oriented hydrogen-induced cracking, and blistering. In each of these processes, anhydrous hydrogen fluoride reacts with the surface of carbon steel and releases atomic hydrogen. When released, atomic hydrogen can diffuse into the steel and pass through it. However, when a single hydrogen atom encounters an internal void space or a flaw (an inclusion) in the steel, it will combine with other atoms to form molecular hydrogen. Molecular hydrogen cannot pass through the steel and becomes trapped in the flaw. DuPont indicated that hydrogen-assisted stress corrosion cracking can occur rapidly and is known to attack weld material having a hardness above Rockwell C 22. Also, areas of flat circular fractures centered around cavities containing inclusions are typical of stress-oriented hydrogen-induced cracking, which can occur in the heat-affected zones of welds.

---

[3] The Rockwell C hardness scale is used for rating the hardness of steels. Higher values indicate higher hardness.

[4] Schuyler, Roy L., III, Ph.D., *Hydrogen Blistering of Steel in Anhydrous Hydrofluoric Acid*, National Association of Corrosion Engineers, Houston, Texas, March 1979.

In the case of tank car ACAX 80010, given the initiation of the crack on the surface of the weld material exposed to the anhydrous hydrogen fluoride and the rapid propagation of the crack through the harder weld material, while the crack arrested in the lower hardness shell and patch material, the National Transportation Safety Board concludes that tank car ACAX 80010 failed because of the hydrogen-assisted cracking of the weld material for the repair patch in the tank shell. Given the susceptibility of high hardness weld material to hydrogen-assisted cracking and the rapid development of through cracks in tank cars transporting anhydrous hydrogen fluoride, the Safety Board believes that the FRA should inform all tank car repair facilities of the circumstances of this accident and urge these facilities to review and modify, if necessary, their practices for heat treatment and hardness testing of weld repairs to prevent additional tank car weld failures from hydrogen-assisted cracking.

While not directly related to the cause of this accident, damage caused by the third form of hydrogen-assisted cracking – blistering – necessitated the February 1997 repair on tank car ACAX 80010. Blistering, according to the DuPont study, primarily affects low-carbon steels and occurs when atomic hydrogen combines to form molecular hydrogen along well-developed planes of impurities in the steel. These planes of impurities usually run parallel to the surface, near the mid-plane of the steel plate. As molecular hydrogen forms along the planes of impurities, the pressure increases, eventually developing sufficiently to expand the flaw and separate a localized area in the steel into two thinner plates, distorting one of the exterior surfaces. The distortion is called a "blister."

In 1979, DuPont provided information to the Association of American Railroads (AAR) that included material concerning the effect that anhydrous hydrogen fluoride has on carbon steel. Because of the information provided by DuPont, the AAR, with the help of the Chemical Manufacturers Association (CMA), began collecting information about hydrogen blistering in tank cars transporting anhydrous hydrogen fluoride. A March 13, 1985, letter from the CMA to the AAR stated that 132 of the 212 tank cars in anhydrous hydrogen fluoride service had been inspected and that the inspections indicated that hydrogen blisters developed slowly in most tank car materials. The letter also stated that blisters could be identified during the required periodic visual inspections and repaired before they threatened tank car integrity. However, the letter indicated that tank cars manufactured of TC 128 steel were the exception to this rule because 22 of the 29 TC 128 steel tank cars inspected had developed hydrogen blisters after only 3 years in anhydrous hydrogen fluoride service.

On the basis of this information, in 1987, the AAR amended the AAR *Manual of Standards and Recommended Practices* (M-1002) to forbid the use of TC 128 steel for repair patches on tank cars in anhydrous hydrogen fluoride service and to forbid the conversion of tank cars made of TC 128 steel to anhydrous hydrogen fluoride service. The new AAR standards also limited the types of steels that could be used in the manufacture of new tank cars for anhydrous hydrogen fluoride service to specification ASTM A516-71, grade 70 normalized steel, and ASTM A537-69, class 1 (normalized) steel. The new standards effectively forbade the use of TC 128 steel in new tank car construction. They did not, however, limit the use of those tank cars made of TC 128 steel that were already in anhydrous hydrogen fluoride service.

The AAR could not provide information on why the prohibition was not applied to tank cars already in anhydrous hydrogen fluoride service. The March 1985 CMA letter, however, had stated that only one tank car made of TC 128 steel was still in anhydrous hydrogen fluoride service and that the industry had no intention of placing additional cars made of that steel in this service. This statement may have been interpreted as an indication that the industry was removing all tank cars made of TC 128 steel from anhydrous hydrogen fluoride service.

Tank car ACAX 80010, a DOT specification 112A400W tank car,[5] was constructed of TC 128 steel. It was 1 of 26 tank cars made of TC 128 steel that had been transferred in 1994 from the Allied-Signal, Inc., Amherstburg fleet in Canada to the company's fleet in Geismar, Louisiana.[6] These tank cars were in Canada when the CMA study was conducted; therefore, it is probable that they were not included in the study.

Allied-Signal, Inc.'s, records of its 26 tank cars made of TC 128 steel do not indicate rapid development of hydrogen blisters in these tanks. In fact, the inspections of tank car ACAX 80010, which had been manufactured in 1971, did not reveal large internal hydrogen blisters until 1996, about 25 years after the tank car was manufactured. However, the Board's investigation revealed a recent increase in the frequency of blister development in this tank car. No blisters were observed during a 1991 inspection, but two were found during a 1996 inspection. During a 1998 postaccident inspection, four additional blisters were discovered.

Given that exposure of TC 128 steel to anhydrous hydrogen fluoride is known to cause the formation of hydrogen blisters that could weaken areas in the tank shell, that the AAR has prohibited the use of TC 128 steel for the construction of new tank cars and for the repair of existing tank cars used to transport anhydrous hydrogen fluoride, that older tank cars made of TC 128 steel may be experiencing an increased frequency of blister development, and that the DOT has assigned anhydrous hydrogen fluoride to those materials (Packing Group I) within the corrosive classification that represent the greatest hazard in transportation and require the strongest packaging, the Safety Board concludes that the use of tank cars made of TC 128 steel is not appropriate for the transportation of anhydrous hydrogen fluoride. Therefore, the Safety Board believes that the FRA should prohibit the transportation of anhydrous hydrogen fluoride in tank cars manufactured of TC 128 steel.

As a result of this investigation, the National Transportation Safety Board recommends that the Federal Railroad Administration:

> Inform all tank car repair facilities of the circumstances of the April 2, 1997, failure of a railroad tank car and release of anhydrous hydrogen fluoride in Memphis, Tennessee, and urge them to review and modify, if necessary, their practices for heat treatment and hardness testing of weld repairs to prevent additional tank car weld failures from hydrogen-assisted cracking. (R-98-67)

---

[5] In 1990, head shields were added to the tank car, and it was converted to a specification 112S400W car.

[6] Information provided by Allied-Signal, Inc., since the accident indicates that the 26 tank cars have been returned to Canada.

Prohibit the transportation of anhydrous hydrogen fluoride in tank cars manufactured of TC 128 steel. (R-98-68)

Please refer to Safety Recommendations R-98-67 and -68 in your reply. If you need additional information, you may call (202) 314-6463.

Chairman HALL, Vice Chairman FRANCIS, and Members HAMMERSCHMIDT, GOGLIA, and BLACK concurred in these recommendations.

By: Jim Hall

Jim Hall
Chairman